PERGAMON

Renewable and Sustainable Energy Reviews
4 (2000) 375–430

Renewable
& Sustainable
Energy Reviews

www.elsevier.com/locate/rser

Present and prospective role of bioenergy in regional energy system

T.V. Ramachandra*, N.V. Joshi, D.K. Subramanian

Centre for Ecological Sciences, Indian Institute of Science, Bangalore, 560012, India

Received 15 February 1997; accepted 20 March 2000

Abstract

Bioenergy is the energy released from the reaction of organic carbon material with oxygen. The organic material derived from plants and animals is also referred to as biomass. Biomass is a flexible feedstock capable of conversion into solid, liquid and gaseous fuels by chemical and biological processes. These intermediate biofuels (such as methane gas, ethanol, charcoal) can be substituted for fossil based fuels. Wood and charcoal are important as household fuels and for small scale industries such as brick making, cashew processing etc. The scarcity of biofuels has far reaching implications on the environment. Hence, expansion of bioenergy systems could be influential in bettering both the socio-economic condition and the environment of the region. This paper examines the present role of biomass in the region's (Uttara Kannada District, Karnataka State, India) energy supply and calculates the potential for future biomass provision and scope for conversion to both modern and traditional fuels. Based on the detailed investigation of biomass resource availability and demand, we can categorise the Uttara Kannada District into two zones (a) Biomass surplus zone consisting of Taluks mainly from hilly area (b) Biomass deficit zone, consisting of thickly populated coastal Taluks such as Bhatkal, Kumta, Ankola, Honnavar and Karwar. Fuel wood is mainly used for cooking and horticulture residues from coconut, arecanut trees are used for water heating purposes. Most of the households in this region still use traditional stoves where efficiency is less than 10%. The present inefficient fuel consumption could be brought down by the usage of fuel efficient stoves (a saving of the order of 27%). Availability of animal residues for biogas generation in Sirsi, Siddapur, Yellapur Taluks gives a viable alternative for cooking, lighting fuel and a useful fertiliser. However to support the present livestock population, fodder from agricultural residues is insufficient in these Taluks. There is a need to supplement the fodder

* Corresponding author. Tel.: +91-080-3600985; fax: +91-080-3601428.
E-mail address: cestvr@ces.iisc.ernet.in (T.V. Ramachandra).

PII: S1364-0321(00)00002-2

availability with fodder crops as successfully tried in Banavasi village by some progressive farmers.

Keywords: Bioenergy; Fuel wood consumption; Integrated energy planning; Energy efficient devices; Per capita fuel consumption; Techno economic analyses; Biogas; Wood gasification; Energy plantation

1. Introduction

Biomass refers to solid carbonaceous material derived from plants and animals. These include the residues of agriculture and forestry, animal wastes and wastes from food processing operations. A small amount of solar energy is used by plants in the process of photosynthesis and this trapped energy can be used in various ways. Wood and grass can be dried and then burnt to release heat. Plant material particularly rich in starches and sugars such as sugarcane, wheat etc., can be fermented to produce ethanol. Alternately, methanol can be produced by the distillation of biomass which contains considerable cellulose such as wood and bagasse (residue from sugarcane). Both of these alcohols can be used to fuel vehicles and machinery, and can be mixed with petrol to make a petrol/alcohol blend. Although biomass energy use is predominantly in rural areas, it also provides an important fuel source for the urban poor and many rural, small and medium scale industries. In order to meet the growing demand for energy, it is imperative to focus on efficient production and uses of biomass energy to meet both traditional (as a heat supplier) and modern fuel requirements (such as electricity and liquid fuels). This production of biomass in all its forms for fuel, food and fodder demands environmentally sustainable land use and integrated planning approaches.

Detailed planning would be required from National, to State, to District, to Taluk and Village levels. The inappropriate selection and site matching of species or management strategies can have adverse effects and lead to the degradation and abandonment of land. However, the correct selection of plant species can allow the economic production of energy crops in areas previously capable of only low plant productivities. Simultaneously multiple benefits may accrue to the environment. Such selection strategies allow synergistic increases in food crop yield and decreased fertiliser applications while providing a local source of energy and employment [1–3]. In this paper, the resource base in Uttara Kannada District under each sector such as forests, agriculture, horticulture and animal residues are explained Talukwise. Also, an attempt is made to illustrate the present role of biomass energy, the resource base for future development and some promising conversion technologies and uses. Biogas, wood based steam power generation, energy plantation and biomass gasification are the most promising bioenergy technologies.

1.1. Present role of bioenergy

Bioenergy is one of the primary sources of fuel in our country. A recent study by the authors on energy utilisation in Karnataka considering all types of energy sources and sectorwise consumption revealed that traditional fuels such as firewood (7.440 million tonnes of oil equivalent — 43.62%), agro residues (1.510 million tonnes of oil equivalent — 8.85%), biogas, cowdung (0.250 million tonnes of oil equivalent — 1.47%) accounts for 53.20% of the total energy consumption in Karnataka. In rural areas the dependence on bioenergy to meet the domestic requirements such as cooking and water heating purposes are as high as 80–85%. Fuel wood and agricultural residues are also widely used as fuel in rural industries such as cashew processing and other agro processing industries, brick kilns, and in commercial sectors such as hotels etc. Detailed investigation of energy consumption in 90 villages in Kumta Taluk reveals that annual per capita fuel wood consumption for domestic purposes such as cooking, water heating etc., is in the range of 0.7–1.1 tonnes and in rural industries such as cashew processing, fuel wood consumption is in the range of 4.5–8.5 kg per kg of cashew kernels. One tonne of fuel wood (logs) for processing 5 tonnes of sugar cane (for making jaggery), 400–800 kg of fuelwood for making 1000 bricks etc.

2. Bioenergy

2.1. Resources from forests

The District of Uttara Kannada is situated between lat 13°55'N and 15°31'N and long 74°9'E and 75°4'E, and covers an area of 10,291 km^2 (Fig. 1(a)) and is subdivided into 11 Taluks that can be grouped according to their geographical characteristics:

- The coastal region, which has hot and humid climate (rainfall varies between 2500–3556 mm) and comprises the Taluks of Karwar, Ankola, Kumta, Honnavar and Bhatkal.
- The hilly region of the Western Ghats (500–1000 m high), which is very humid to the south (rainfall varies from 3048–3556 mm) and comprises the Taluks of Sirsi, Siddapur, Supa and Yellapur.
- The region of transition, which is drier (rainfall varies between 1016–1524 mm), and comprises the Taluks of Mundgod and Haliyal.

This geographical diversity is responsible for the growth of four vegetation types found throughout the District:

- Evergreen forest type, found mainly in Sirsi, Siddapur and the hilly eastern region of Honnavar, Kumta, Ankola and Karwar.
- Semi deciduous forest type, on the slopes of Ankola, Kumta, Karwar, Honnavar, Siddapur and Sirsi.

(a)

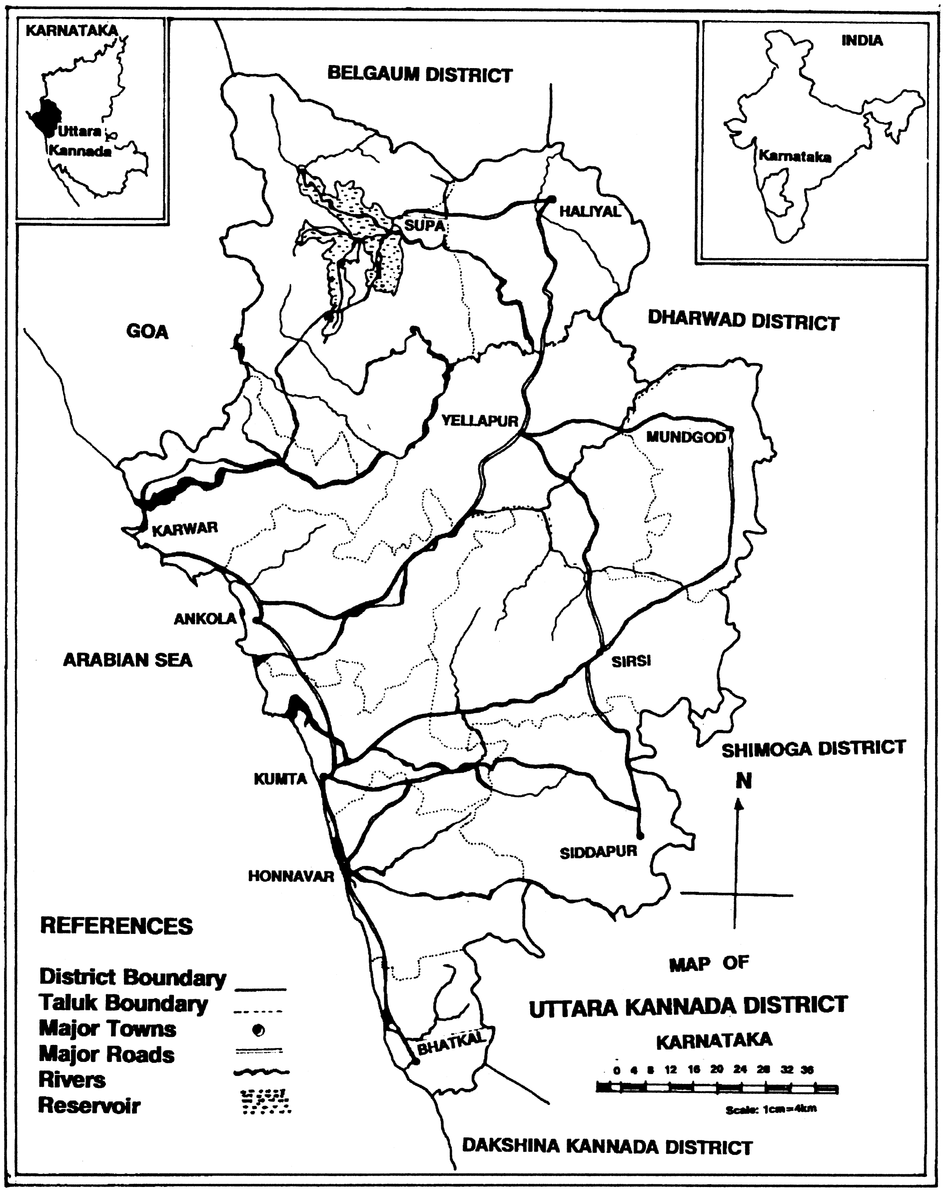


Fig. 1(a). Geographical location of Uttara Kannada District.

- Deciduous forest type, in Haliyal, Supa and Mundgod.
- Moist deciduous forest type, in Ankola, Bhatkal, Yellapur, West Karwar and the coastal region of Kumta.

About 80.58% of the District's geographical area is under forests (8292.65 km^2). The per capita forest area is about 0.64 hectares and per capita land area is about 0.83 hectares. Total geographical area in hectares, population as per 1991 census, area under forests, per capita land area, per capita forest area and the ratio of forest area to total land area — Talukwise, are listed in Table 1. It is seen that Bhatkal among coastal Taluks is thickly populated (3.61 persons/hectare) while, Supa Taluk is very thinly populated (0.53). Table 1 also provides information on Talukwise vegetation cover. Yellapur Taluk has 87% vegetation cover while the minimum cover of 67% is in Kumta. This information is shown pictorially in Fig. 1(b). The forest area according to legal status in the District could be classified as (1) reserve forests (7727.84 km^2, 93.18% of total forest area) (2) protected forests (542.77 km^2) (3) village forests (20.20 km^2) (4) unclassified forests (1.84 km^2).

A significant majority of people in Uttara Kannada meet the bulk of their resource needs from plant and animal matter, either gathered directly from non cultivated land (from forests) or water, or produced on crop lands and orchards mostly under rainfed conditions. The needs of biomass in this region varies from a wide range of needs apart from fuel, fodder and food. Madhav Gadgil [4] in his

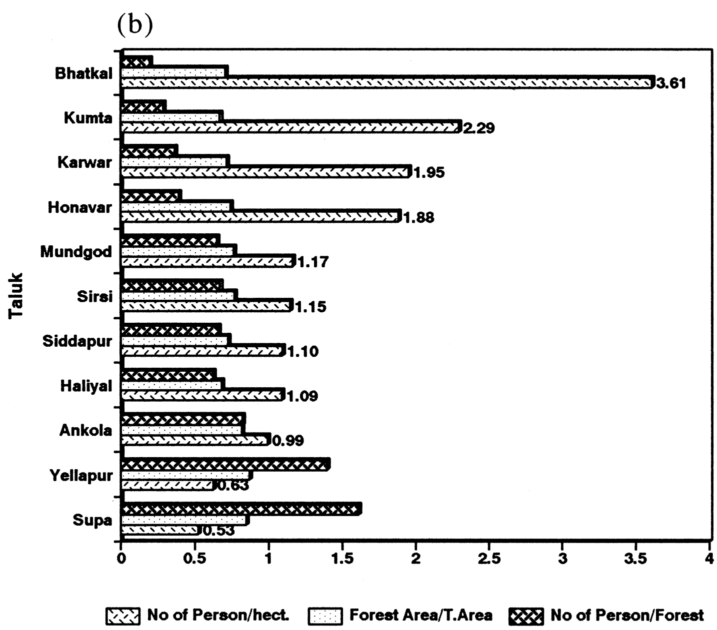


Fig. 1(b). Population, geographical area forest area (in hectares).

Table 1
Population (1991), total area, area under forests in Uttara Kannada

TALUK	Total area (km^2)	Total area (ha)	Population total (1991)	Forest (ha)	No of persons per geo. area	Forest/total area	Forest area/person	Total area/person
Supa	1895.1	189,514.23	99,519	160,609	0.53	0.85	1.61	1.90
Yellapur	1301.1	130,110	81,410	113,430	0.63	0.87	1.39	1.60
Ankola	918.7	91,870	91,310	75,432.4	0.99	0.82	0.83	1.01
Haliyal	864.9	86,489.33	94,363	59,099.8	1.09	0.68	0.63	0.92
Siddapur	859.3	85,930	94,202	62,274.6	1.10	0.72	0.66	0.91
Sirsi	1333.4	133,342.62	152,935	103,227	1.15	0.77	0.67	0.87
Mundgod	668.9	66,890	77,939	51,167.4	1.17	0.76	0.66	0.86
Honavar	775.5	77,546.13	145,842	57,416.7	1.88	0.74	0.39	0.53
Karwar	732.1	73,210	142,845	52,808.7	1.95	0.72	0.37	0.51
Kumta	584.9	58,486.81	134,144	39,187.6	2.29	0.67	0.29	0.44
Bhatkal	357.3	35,731.96	129,017	25,390.5	3.61	0.71	0.20	0.28
District	10,291.2	1,029,121.08	1,243,526	800,042	1.21	0.78	0.64	0.83

report, has listed 80 different plant species from natural vegetation used for purposes ranging from food, condiments, masticatories, fuel for domestic cooking, bath water heating, agro processing, fodder for livestock, thatch and small timber for houses and cattlesheds, matting for protecting the houses during the rainy season, poles for fencing, leaf manure for fields and orchards, mulch for weed control, leaves for the control of insect pests, wood for the manufacture of wood carts and agricultural implements, fishing traps, brooms, mats, baskets, ropes, idols and garlands and decorative articles. This dependence on biomass from non-cultivated lands or rainfed cultivation is mainly due to necessity, apart from diverse tradition.

2.2. Working plans

During colonial rule, the concept of working plans were established in India (1890) to document the forest policies of the State, scientific and rational forest management. The working plans prepared so far since 1890 focus mainly on ecological information of the area, floristic information, the forest produce and its market potential, availability of labour, growth and yield statistics, technical proposals for future management, details of felling succession, financial forecast and the cost of the plan. The choice of the criteria in working plans, although subjective, is intended to give an accurate view of the forest policy and the management system followed. Scanning through all the working plans reveals that they have been concentrated in some areas such as the valleys of the Kalinadi, Gangavali, Aghnashini and Sharavati rivers, because of easier access to the banks from the river and cheaper transport facilities. Also most of the wood depots were either located on the coasts at the river mouths or nearby places such as Kodibag, Karwar, Honnavar, Bhatkal etc. or above the Ghats, near the logging sites such as Kirwatti, Londa, Haliyal, Dandeli. The second major area of interest is the drier tract of Haliyal, Mundgod which was easily accessible and also contained rich deciduous species like Teak (*Tectona grandis*), Nandi (*Lagerstroemia microcarpa*), Honne (*Pterocarpus marsupium*), Kindal (*Terminalia paniculata*), Matti (*Terminalia tomentosa*), Dindal (*Anogeissus latifolia*), and Jungle wood. The limitation of the economically interesting species to a small proportion of the total forest could have been helpful to sustainable management if the foresters would have contented themselves only to the felling of these species. But the silvicultural systems followed actively discouraged the growth of non economic species to the detriment of the floristic wealth of the tropical forest.

2.3. Vegetation types in the Uttara Kannada District

Flora of the Uttara Kannada Forests were studied by various persons. Buchanan [5] in his book, gives a brief account of the plants encountered in the course of his journey through this District. Botany of Uttara Kannada forests of recent times is provided by Talbot [6]. A good deal of floristic information on

coastal, interior and inland high forest is available from the forest working plans [7–10]. Denudation of the Kanara coast is well accounted by Dhareshwar [11].

Recently Subash Chandran, [12] after a detailed survey of various types of forests in Uttara Kannada, linked the forest composition with management of the forest ecosystem and makes certain recommendations for most sustainable utilisation of forest resources and betterment of the degraded forest ecosystem. He also discusses the effect of slash and burn agriculture practiced in the interior hills and its subsequent ban by the close of the 19th century, on forest composition. He highlights the return of evergreen forests with the stoppage of slash and burn agriculture. The return of evergreens is considered one of the major factors for the reduction of the incidence of deciduous trees like *Tectona grandis* from the evergreen forest belt. The Forest map of South India [13], published by Institu Francais de Pondicherry covering Belgaum-Dharwar-Panaji, Shimoga are used to identify the vegetation types in the Uttara Kannada District. Secondary moist deciduous forest could be seen in the river valleys of Kali, Gangavali and Aghnashini. These are secondary forests as the evergreen patch in this region is clear felled as part of the government's Working Plans in the early 19th century. Many such patches — yellow in colour — could be seen with the evergreen forest fragments. From this analyses, it is evident that the percentage evergreen patch is about 51.1%, the moist deciduous type is 23.2%, the dry deciduous type is 8.6%, and the coastal is 17.1%

The forests are divided according to convenience of administration by the Forest Department as follows:

1. Reserve forests maintained by the Forest Department.
2. Forest plantations maintained by the Forest Department. Out of those areas notified under the Forest Act, the barren lands and hillocks that are denuded of tree growth are being afforested by raising plantations like cashew, etc.
3. Reserve forests under Section 4 of the Karnataka Forest Act.
4. Revenue plantations maintained by the Revenue Department representing the afforestation works done in the unreserved lands for which a notification under Section 4 of the Act is issued.
5. Unreserved lands are maintained by the Revenue Department. Protection and management of tree growth in unreserved kinds are vested with the Forest Department. Suitable areas of reserved kinds are vested with the Forest Department. Suitable areas of unreserved lands in compact blocks have been surveyed and demarcated and the notification under Section 4 of the Act has been issued for constituting them as reserve forests.
6. Several panchayats in the recent years have commenced maintaining certain areas of wastelands to develop forests under the scheme "Farm Forestry" which envisages the creation of fuel reserves to help people to get their supply of fuel, small-sized timber to meet their agricultural demands and to provide green manure, fodder and grazing to village cattle.

Table 2 gives details of forest area according to legal status as in 1980–1981 in the District.

Table 2
Details of forest area according to legal status as in 1980–1981 in the District

Forest types	Area (km^2)
Reserve forests	7727.84
Protected forests	542.77
Village forests	20.2
Unclassified forests	1.84
Total	8292.65

2.4. Loss of forest area

The increasing population has a direct bearing on the increased demand for agricultural lands and this has always an adverse effect on valuable forests. Unauthorised cultivation poses a serious problem. The high tension electricity lines riddling the forests, increased communications, settlement of expropriated ryots and refugees on release of lands for irrigation and hydro-electric projects have a heavy impact on forests. People settling down in colonies in the interior depend on forests for their requirement of timber and firewood. Grazing also has deleterious effect on forests. The release of forest lands has now been discouraged and any such proposal has to be approved by both the Houses of Legislature. According to the recently enacted Central Forest Conservation Act, no forest land can be released for non-forestry purpose in the State without specific approval of the Government of India. Table 3 gives the purpose and the areas so far lost in the District.

Pascal [14], classifies vegetation in this region as follows:

1. Group I — Evergreen or semi evergreen climax and potentially related forests:
   (a) Evergreen or semi evergreen climax and potentially related forests
      (1) Low elevation (0–850 m in the south and 0–650 m in the north).

Table 3
The purpose and the areas lost in the District

Purposes	Extent lost (in ha)
Area gone under submersion	304
Area released for rehabilitation	4202
Area gone under power lines	626
Area given for cultivation	50,158
Area gone for mining	26,713
Area given for townships	1097
Area given for non agricultural purpose	7383
Area lost under the Kali Power Project	14,176
Area lost under the Bedthi Project	300
Area lost for colony and roads	273
Total	105,232

Dipterocarpus indicus-Diospyros candolleana-Diospyros oocarpa type: Honnavar and Kumta (scanty distribution);
Persea macrantha-Diospyros spp.-Holigarna type: Honnavar and Kumta;
Diospyros spp-Dysoxylum malabaricum-Persea macrantha kan forest type: Eastern Sirsi.

(2) Medium elevation (650–1400 mm).
Transition type: Supa, Joida; *Memecylon umbellatum-Syzigium cumini-Actinodaphne angustifolia* type.

(b) Secondary or degraded stages
(1) Evergreen and semi evergreen forests.
Disturbed low elevation: all Taluks except Haliyal and Mundgod.
Disturbed transition: Supa, Joida.
Secondary low elevation: Bhatkal, Honnavar, Kumta, Sirsi and Siddapur.

(2) Secondary moist deciduous forests.
Dense forest: Joida, Yellapur, Sirsi.
Woodland to savanna woodland: all except Haliyal and Mundgod.

(3) Other degraded stages.
Thicket low elevation: all except Haliyal and Mundgod.
Thicket medium elevation: Supa, Joida.
Tree savanna to grass savanna low elevation: all except Haliyal and Mundgod.
Scattered shrubs low elevation: Bhatkal, Honnavar, Kumta, Ankola, Karwar.

2. Group II — Deciduous climax forests and degradation. Occur in North eastern parts of the District.
3. Group III — Plantations. *Acacia catechu, Casuarina equisetifolia, Eucalyptus spp., Tectona grandis.*
4. Group IV — Scrub type is common along the minor forest tract which runs as a belt of 8–16 km along the coast.

2.5. Types of vegetation in various Taluks

Talukwise distribution of various vegetation [15,16] are discussed in the following section:

2.5.1. Ankola Taluk

In Ankola Taluk, as one goes from east to west, forest types changes from laterite thorn to moist deciduous, laterite semi-evergreen in nala pockets and interior depression. The western part which adjoins the coast is also denuded to unrestricted exercise of privileges and due to kumri (shifting) cultivation in the past. The inland areas of moist deciduous and semi-evergreen are closed as fuel forest and high forest areas, yielding firewood and timber respectively. Round about Hattikeri, in laterite thorn forests, one can come across the khair trees (*Acacia catechu*) which yield valuable economic forest produce called katha. The Gangavali river valley area supports valuable teak forests having the most common under growth, bamboo.

2.5.2. Bhatkal Taluk

The type of forests in Bhatkal Taluk changes from laterite thorn to laterite evergreen. There is very little moist deciduous forest. The barren hills around Murdeshwar and Bhatkal are a testimony to the acts of unrestricted fellings. As one goes into the interior, the vegetation improves gradually. The evergreen forests round about Kop village in the north-east part of the Taluk contain valuable timber for matches and plywood. The laterite thin forests situated in the north-west and south-west of the Taluk contain a large number of khair trees. These are bigger in the girth in the Balke forests in the south-west part of the border of the Dakshina Kannada District.

2.5.3. Haliyal Taluk

The eastern and north-western parts of Haliyal Taluk comprise a teak pole area tending to scrub type towards the border of the Dharwad District. The forest towards the western half of this Taluk are constituted at High Forests, yielding valuable teak timber. The timber extracted from these high forest areas is transported to the Dandeli and Alnavar forest depots. There is sandalwood in drier parts of the area and this is extracted annually on a sustained yield basis. There are patches of evergreen forest towards the western side in the lower portions of the valleys of rivers and perennial nalas. Bamboo is considered as one of the most valuable constituents of economic forest produce.

2.5.4. Honnavar Taluk

In the Honnavar Taluk, the forest type changes from laterite to laterite semi-evergreen and evergreen. There is very little of the moist deciduous type which can be seen only on tops of small hills in the western part of the belt. The coastal strip of the forests is all denuded and in many parts, the land has become unfit even to bear poor grass. As one advances in the interior, the forest growth improves gradually. These forests contain valuable timber trees like poon, ganjan, bobbi, honne, kindal, jamba, nandi, bharangi and others, suitable for matches and plywoods. The laterite semi-evergreen forests and evergreen forests in the north-east corner, in the Mahime and Jankadkal villages of the Taluk, contain tale palms. The belt of *Acacia catechu* also passes in this Taluk, mostly confined to the

south-west part of the Taluk. The evergreen forests of Gerusoppa contain varieties of canes which are exported outside the District.

2.5.5. Karwar Taluk

In Karwar Taluk, as one goes from west to east, the forest types gradually changes from laterite thorn to moist deciduous and laterite semi-evergreen to evergreen. The forests to the west of Honkane village have been depleted due to the unrestricted exercise of privileges. The deciduous forests in the lower slopes tend to be towards high forests, yielding valuable timber of teak, sissum, honne, kindal, etc. Jamba is the predominant species of this tract. The upper slopes and lower valleys and banks of perennial nalas contain patches of evergreen forests and large quantities of canes (*Calamum*) that are exported to various places. The upper slopes are not worked due to their inaccessibility. Reserved forests of the moist deciduous type in the patches of laterite semi-evergreen in the interior situated on the steep hills round Karwar had been classified as "Karwar Town Five Miles Special Reserves".

2.5.6. Kumta Taluk

In the Kumta Taluk, the types of forest change from laterite thorn to moist deciduous, laterite semi-evergreen and evergreen as one advances from west to east as is the case in other Taluks. The timber bearing high forests are confined to the south-east part of the Taluk at the foot of the Nilkund and Dodmane Ghats round about the Soppinahosahalli village. Around Mirjan, the laterite thorn forests contain khair trees which yield valuable catechu. Bamboos occur in the Aghanashini valley around Soppinahosahalli.

2.5.7. Mundgod Taluk

The forest type in Mundgod Taluk changes from scrub in the south-west near the Sirsi Taluk boundary. The stock improves as one advances from east to west. The eastern half is comprised of a teak pole area and the western half is in the high forest area. The deep valleys, in the south-west and the perennial nala belts are covered with patches of semi-evergreen forests. The drier parts of the teak pole arch, towards the border of the Dharwad District, contain sandalwood.

2.5.8. Siddapur Taluk

Owing to the scanty growth in the eastern side and also to the major part of Siddapur Taluk being very hilly, no part is organised except the area covered by sandalwood trees towards the north-east, east and south-east. This sandalwood belt extends to Sirsi, Mundgod Taluks also. The eastern part is drier and as one advances from east to west towards the Ghats, the forest type improves to semi-evergreen. There are many large patches of evergreen forests called kans in this Taluk, mostly confined to the west round about Dodmane, Nilkund and Malemane Ghats. These contain valuable matchwood, the extraction of which will be economical only when communications are improved.

2.5.9. Sirsi Taluk

The forest of Sirsi Taluk are firstly semi-evergreen and evergreen types. The evergreen forests are attached here and there all over the area. The belt of sandalwood forest of Siddapur Taluk runs over this Taluk and is mostly confined to the south-eastern part bordering Siddapur Taluk and the Shimoga District.

2.5.10. Supa Taluk

The greater part of the Supa tract is very hilly and preciphorous. The forest area falls into two different types of forests. The south-eastern part of this Taluk contains high forests, near Gund and portions of the Nagjhari valley and the Kalinadi and the Kaneri slope forests, yielding mainly timber of valuable species. Gund has the finest teak plantations. Evergreen patches are also found in the valleys. The forests of the northern point near Castlerock yields only fuel and it merges into scrub forests, wherever the soil is very poor. Bamboo grows abundantly in this Taluk.

2.5.11. Yellapur Taluk

The northern parts of the Yellapur Taluk is a valuable forest of teak. Bamboo is also plentiful here, confined to the catchment area of Gangavali. The bamboo belt extends to Ankola Taluk also.

With the knowledge of vegetation in each Taluk, we try to estimate the litter and above ground biomass availability in the Uttara Kannada District.

3. Litter production in tropical moist forests of Western Ghats

Based on a three year study in Attapadi evergreen forests, Pascal [17] estimates that the total mean production of litter is 8.5 t/ha/year, that of leaves and foliar fragments is 6.4 t/ha/year which is nearly 74.75% of total production.

Recent study on litter production in the Uttara Kannada forests is by Bhat [18] at Sonda reserve forest (percentage composition of evergreen species 44.77%, deciduous species 55.23%), Santgal reserve forest (percentage composition of evergreen species 86.76%, deciduous species 13.24%), Nagur reserve forest (percentage composition of evergreen species 66.66%, deciduous species 33.34%) and Bhairumbe leaf manure forest (percentage composition of evergreen species 43.83%, deciduous species 56.17%). The estimation of micro litterfall (leaf matter, reproductive parts, small wood $\leq$ 2 cm diameter), total ground litter (micro litter and dead herbs), large wood litterfall (wood between 2–10 cm) based on two years study are given in Table 4. In all sites studied, leaf litter is a major component which constitutes 65–92% of the total micro litter and 75–94% of the total ground litter. The micro litter estimated by others in the similar type of vegetation is 8.8–12.0 t/ha/year [19], 6.00 t/ha/year [20], 3.44–4.20 t/ha/year [21], 12.9–14.1 t/ha/year [22].

4. Estimation of standing biomass and biomass productivity

To estimate standing biomass of any vegetation (tree), we have to have the knowledge of the Girth of a tree (at 130 cm height also referred as GBH), height of a tree, branch diameter etc. These parameters are required to compute the relationship between standing biomass and tree dimensions. The practice so far followed for this purpose is:

1. Destructive sampling (some sample trees are cut which belong to the same species, and woody components of the tree are measured).
2. Computing the volume of a tree by actual measurement: that is actual measurement of all woody components of tree and its shape.
3. Referring to all available literature.

Standing biomass and biomass productivity from forests in all Taluks of the Uttara Kannada District are estimated by adopting the relationship, and productivity data available in the literature. Other methods for this purpose through destructive sampling (socially unacceptable), or through non destructive sampling (time consuming) involves primary survey and long term monitoring which is unnecessary as my colleagues at the Centre for Ecological Sciences have already carried out a long term monitoring (since the early 80's) of sample plots (study plots of 1 ha size) in this region and have published on these aspects. Also other researchers such as S. N. Rai of the Karnataka Forest Department has carried out research in this region based on data from evergreen forest sites that were clear felled (submergence due to hydro electric projects).

Greenland and Kowal [23] estimate above ground biomass in the Khade tropical forest, Ghana, as 265.8 t/ha. Whitemore [24] studies in the tropical forests

Table 4
Litter productivity in tropical moist forests of Uttara Kannada District

Place	Type	Production (t/ha/year)
Sonda	Micro litterfall	9.78 ± 3.20
Bhairumbe	Micro litterfall	6.78 ± 1.62
Santgal	Micro litterfall	10.24 ± 0.22
Nagur	Micro litterfall	8.29 ± 0.95
	Average	8.04 ± 0.88
Sonda	Ground litter	21.14 ± 4.71
Bhairumbe	Ground litter	10.37 ± 2.98
Santgal	Ground litter	19.16 ± 0.82
Nagur	Ground litter	15.77 ± 1.94
	Average	15.44 ± 1.74
Sonda	Wood litterfall	0.41 ± 0.08
Bhairumbe	Wood litterfall	0.71 ± 0.02
Santgal	Wood litterfall	1.24 ± 0.36
Nagur	Wood litterfall	0.61 ± 0.24
	Average	0.62 ± 0.16

of Malaysia gives a standing biomass in the range of 230–290 t/ha. Rai's [25] study in Western Ghats at the locations of Agumbhe, Bannadpare and Kagneri gives an average standing above ground biomass of 485.67 t/ha (by using the relationship $V = 0.0790 + 0.4149\ D^2H$, where V = volume of stem wood, D = diameter at breast height (at 130 cm), H = stand height). Also based on the measurements of basal area of four preservation plots in the Uttara Kannada District, Rai has arrived at an annual basal area increment of 2%. Narendra Prasad [26] estimates average standing biomass in the reserve forests at Nagur, Santgal (Kumta Taluk) and Sonda, Bidralli (Sirsi Taluk) as 243.25 t/ha. And average standing biomass estimates for minor forests at Bengle, Bhairumbe (at Sirsi), Chandavar, Mirzan (Kumta) is 129.92 t/ha. Lele [27] using the regression relationship of $V = 0.0250 + 0.5\ D^2H$, estimates the standing biomass in leaf manure forests (Soppina betta) at Sirsi in the range of 99–201 t/ha. The variation in the biomass estimated by Pascal according to bio volume (D^2H) obtained from seven sampling plots of 1600 m^2 each, in different vegetation is given in Table 5.

4.1. Net annual above ground productivity (t/ha) of tree layer in reserve forests

The net primary productivity (NPP) for reserve forests at four locations in Western Ghats varies from 6.5 t/ha/year to 11.1 t/ha/year (these values exclude losses due to dead trees). Estimations at sites located in the Uttara Kannada District vary from a minimum of 3.95 t/ha/year to a maximum of 7.25 t/ha/year. And in minor forests, shows a variation of 1.50 t/ha/year to 3.5 t/ha/year. These are summarised in Table 6. Taking into consideration wood litterfall and dead wood trees, the annual above ground productivities computed for various types of vegetation are given in Table 7. This is used to compute the annual availability of woody biomass in the Uttara Kannada District.

4.2. Bioenergy availability from forests and demand in the district

Table 8 lists woody biomass annual availability in various Taluks of the Uttara Kannada District taking into account woody biomass productivity of 3.6 t/ha/year (evergreen, semi evergreen), 3.9 t/ha/year (deciduous) and 0.9 t/ha/year (coastal). While Table 9 lists woody biomass availability based on higher values of

Table 5
Standing biomass in various types of vegetation

Vegetation types	Biomass (t/ha)
Dense evergreen and semi evergreen	518.40–833.22
Low evergreen	226.55
Secondary semi evergreen	226.55
Dense deciduous forest	258.12
Savanna woodland	74.25

Table 6
Estimates of net annual above ground productivity (t/ha)

Forest type	Locality	NPP (t/ha/year) of oven dry matter	Reference
Reserve	Bidralli	3.946	[26]
	Nagur	7.250	
	Santgal	5.296	
	Sonda	5.088	
Minor	Bengle	3.533	
	Bhairumbe	3.314	
	Chandavar	3.476	
	Mirzan	1.501	
Reserve	Agumbe	11.10	[43]
	Bannadpare	6.500	
	Kagneri	9.20	
	South Bhadra	9.500	
Reserve	Malenalli	6.2 (thick veget.)	[27]
		3.6 (medium type)	
		0.9 (low density)	
	Arasapura	6.2 (high density)	
		3.6 (medium type)	
		0.9 (low density)	
Shrublayer			
Reserve	Sonda	1046.88 kg/ha	[26]
	Bidralli	969.75 kg/ha	
	Nagur	224.14 kg/ha	
Herblayer	Minor forest	8.016 ± 3.50 t/ha	
	Reserve	3.150 ± 3.69 t/ha	

productivities such as 13.5 t/ha/year for deciduous, 6.5 t/ha/year for evergreen and semi evergreen) and 1.5 t/ha/year for the coastal region of the District. Based on field data collected from villages in Kumta, Sirsi and Siddapur, fuel demand in this region is found to be approximately 1.1 t/capita/year (higher estimate) and 0.7 t/capita/year (lower estimate). Fuel demand Talukwise computed based on the survey result is listed in the 10th columns of Table 8 and Table 9 respectively. The last columns in these Tables gives the ratio of productivity and fuel wood

Table 7
Biomass productivities in various types of vegetation

Vegetation types	Biomass (t/ha/year)
Dense evergreen and semi evergreen	13.41–27.0
Low evergreen	3.60–6.50
Secondary evergreen	3.60–6.50
Dense deciduous forest	3.90–13.50
Savanna woodland	0.50–3.50
Coastal	0.90–1.50

Table 8
Population (1991), area under different types of vegetation in Uttara Kannada (Talukwise). Production–demand ratio (Talukwise) considering fuel wood demand as 0.7 t/person/year

Taluk	Population total (1991)	Forest (ha)	Dry deciduous	Moist deciduous	Evergreen	Semi evergreen	Coastal	Biomass production	Biomass demand	Prod/demand ratio
Bhatkal	129,017	25,390.46			5078.1	8124.9	12,187.4	58,449.6	141,918.7	0.41
Kumta	134,144	39,187.59		7837.5	11,756.3	7837.5	11,756.3	109,333.4	147,558.4	0.74
Karwar	142,845	52,808.68		10,561.7	15,842.6	10,561.7	15,842.6	147,336.2	157,129.5	0.94
Honavar	145,842	57,416.68		2870.8	20,095.8	17,225.0	17,225.0	160,192.5	160,426.2	1.00
Ankola	91,310	75,432.37		15,086.5	22,629.7	15,086.5	22,629.7	210,456.3	100,441	2.10
Haliyal	94,363	59,099.78	23,639.9	23,639.9	11,820.0			219,851.2	103,799.3	2.12
Siddapur	94,202	62,274.6			40,478.5	21,796.1		224,188.6	103,622.2	2.16
Sirsi	152,935	103,226.57		15,484.0	46,452.0	41,290.6		371,615.7	168,228.5	2.21
Mundgod	77,939	51,167.36	28,142.0	23,025.3				192,645.1	85,732.9	2.25
Yellapur	81,410	113,429.56		51,043.3	62,386.3			408,346.4	89,551	4.56
Supa	99,519	160,608.71		40,152.2	120,456.5			578,191.4	109,470.9	5.28
District	1,243,526	800,042.36	51,782.0	189,701.3	356,995.7	121,922.4	79,641.0	2,680,656.3	1,367,879	1.96

Table 9
Population (1991), area under different types of vegetation in Uttara Kannada (Talukwise). Production–demand ratio (Talukwise) considering fuel wood demand as 1.1t/person/year

Taluk	Population total (1991)	Forest (ha)	Dry deciduous	Moist deciduous	Evergreen	Semi evergreen	Coastal	Biomass production	Demand @ 1.1 t/pers	Production/demand
Supa	99,519	160,608.71		40,152.2	120,456.5			1,031,911.0	109,470.9	9.43
Yellapur	81,410	113,429.56		51,043.3	62,386.3			721,979.1	89,551	8.06
Mundgod	77,939	51,167.36	28,142.0	23,025.3				522,674.6	85,732.9	6.10
Haliyal	94,363	59,099.78	23,639.9	23,639.9	11,820.0			542,536.0	103,799.3	5.23
Sirsi	152,935	103,226.57		15,484.0	46,452.0	41,290.6		666,327.5	168,228.5	3.96
Siddapur	94,202	62,274.6			40,478.5	21,796.1		404,784.9	103,622.2	3.91
Ankola	91,310	75,432.37		15,086.5	22,629.7	15,086.5	22,629.7	372,635.9	100,441	3.71
Honavar	145,842	57,416.68		2870.8	20,095.8	17,225.0	17,225.0	286,222.1	160,426.2	1.78
Karwar	142,845	52,808.68		10,561.7	15,842.6	10,561.7	15,842.6	260,874.9	157,129.5	1.66
Kumta	134,144	39,187.59		7837.5	11,756.3	7837.5	11,756.3	193,586.7	147,558.4	1.31
Bhatkal	129,017	25,390.46			5078.1	8124.9	12,187.4	104,100.9	141,918.7	0.73
District	1,243,526	800,042.36	51,782.0	189,701.3	356,995.7	121,922.4	79,641.0	4,562,742.2	1,367,879	3.34

demand. This ratio at less than one, means that in that Taluk there is fuel wood scarcity while a ratio of greater than one indicates that the Taluk has a surplus of fuel wood. Fuel wood scarcity is evident in thickly populated coastal Taluks namely Karwar (0.94). Kumta (0.74) and Bhatkal (0.41) as listed in Table 8. Taking into account the inaccessibility of dense forests and the degradation of forests closer to the villages, the available biomass computed in Table 8, based on lower productivity values in each type of vegetation, seems to be more realistic than the values computed in Table 9. Talukwise fuel wood available from forests to demand, are shown pictorially in Figs 2 and 3 (are based on computations in Tables 8 and 9).

It appears that in many Taluks household energy consumption doesn't, in itself, trigger the removal of tree cover and land degradation. In fact, where energy demand puts a heavy, directly observable damage on the environment, it is the overall framework of development rather than energy demand of the residential sector which is the prime cause of the problem. In coastal Taluks, the forest based industries and grazing pressure (due to non availability of fodder) and the encroachment and conversion of forest land for other purposes have resulted in a decrease of vegetation cover and barren hill tops.

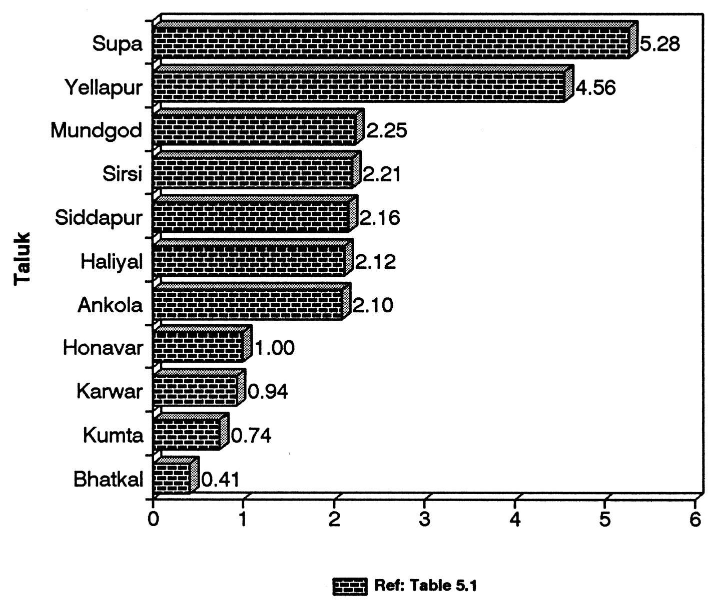


Fig. 2. Availability to demand ratio woody biomass (Talukwise).

5. Bioenergy from agriculture

In this section assessment of residues from major crops such as paddy, oil seeds, maize etc. are carried out.

5.1. Agricultural population in the Uttara Kannada District

As per 1991 census, out of a total number of 428,663 workers, 141,345 are cultivators (32.98%), 82,283 are agricultural labourers (19.19%), and 56,937 depend on livestock and forestry (13.28%). Thus, the population depending on agriculture and allied jobs, amounts to 65.45%. The Talukwise land utilisation for various agricultural crops, production and yield are given in Table 10. The net cropped area in the District is about 1084.28 km^2, which amounts to 10.54% of the total area (compared to 55% of the Karnataka State) as against 12% in 1980–1981. The percentage of the area sown more than once is about 15% of the net area sown. Agriculture and plantation are the major source of District revenue (nearly 50%). It is noticed that paddy yield is at a minimum in Mundgod (0.91 t/ha for improved variety, 1.62 for HY variety). While, it is maximum for Sirsi (3.04 t/ha for HY variety, 1.42 for improved variety) and Siddapur (1.62 t/ha for improved variety). Based on 1984–1985 to 1993–1994 Talukwise crop data, average production (in tonnes), standard deviation and maximum and minimum values for major crops computed are listed in Table 11.

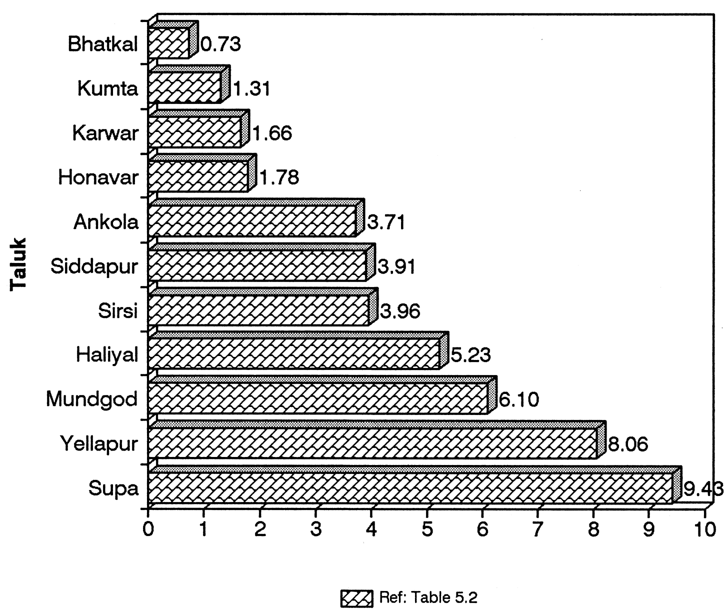


Fig. 3. Availability to demand ratio woody biomass (Talukwise).

Table 10
Area (in hectares), average production and yield for different crops in Uttara Kannada District

	Paddy high yield variety	Improved variety	Ragi	Pulses	Sugarcane	Jowar	Maize	Oil seed	Total
(i) *Area (in hectares) (Talukwise)*									
Ankola	4328	2274	5	291	61			1151	8110
Bhatkal	3468	1322	0	461	74			1048	6373
Haliyal	9666	7188	0	3358	630	125	28	345	21340
Honavar	4184	1585	0	222	192	345	0	1649	8177
Karwar	4242	3079	12	77	16	0	22	143	7591
Kumta	4333	3005	218	183	127	0	0	931	8797
Mundgod	6680	6954	0	904	23	0	0	140	14701
Siddapur	5391	2350	10	142	215		0	33	8141
Sirsi	4725	6469	107	828			0	382	12511
Supa	3661	1745	0	45	260			20	5731
Yellapur	3367	3071		413	84			21	6956
Total	54045	39042	352	6924	1682	470	50	5863	108428
(ii) *Average production (Talukwise)*									
Ankola	11,489.82	2889.91	8.57	103.13	4840.00			1800.56	
Bhatkal	6739.34	1523.29	9.00	185.67	4756.04			2799.95	
Haliyal	17,194.45	7473.86	16.86	1126.15	32,852.29	218.86	110.57	276.29	
Honavar	8202.86	1698.16	6.71	95.82	15,704.00	431.00	0.36	1780.12	
Karwar	10,608.30	4232.36	35.70	54.24	1940.86	31.86	252.79	330.76	
Kumta	9821.14	4522.90	82.74	93.93	7684.18	8.14	3.57	1341.70	
Mundgod	10,848.78	6351.72	2.71	538.08	2932.29	41.00	19.64	180.23	
Siddapur	10,066.04	3851.71	15.97	496.90	13,170.86		18.36	279.50	
Sirsi	14,347.56	9181.39	210.61	380.30			4.07	676.54	
Supa	6036.36	2438.72	6.73	49.78	11,955.00			28.66	
Yellapur	8014.98	5853.02		211.89	6189.71			52.56	
Total	113,369.65	50,017.06	395.61	3335.89	102,025.22	730.86	409.36	9546.86	
(iii) *Average yield (Talukwise)*									
Ankola	2.65	1.27	1.71	0.35	79.34			1.56	
Bhatkal	1.94	1.15		0.40	64.27			2.67	

(continued on next page)

Table 10 (*continued*)

	Paddy high yield variety	Improved variety	Ragi	Pulses	Sugarcane	Jowar	Maize	Oil seed	Total
Haliyal	1.78	1.04		0.34	52.15	1.75	3.95	0.80	
Honavar	1.96	1.07		0.43	81.79	1.25		1.08	
Karwar	2.50	1.37	2.98	0.70	121.30		11.49	2.31	
Kumta	2.27	1.51	0.38	0.51	60.51			1.44	
Mundgod	1.62	0.91		0.60	127.49			1.29	
Siddapur	1.87	1.64	1.60	3.50	61.26			8.47	
Sirsi	3.04	1.42	1.97	0.46				1.77	
Supa	1.65	1.40		1.11	45.98			1.43	
Yellapur	2.38	1.91		0.51	73.69			2.50	
Total	23.66	14.69	8.63	8.91	767.78	3.00	15.44	25.33	

Table 11
Average (avg), standard deviation (Sd), maximum, minimum production (in tonnes), during the period 1984–85 to 1993–94

Crop	Avg	Sd	Max	Min
Paddy (high yield variety)				
Ankola	11,489.82	3159.50	18,513.00	8179.00
Bhatkal	6739.34	785.40	7838.00	5303.00
Haliyal	17,194.45	6315.85	23,607.00	5676.00
Honavar	8202.86	2248.29	11,494.00	3838.00
Karwar	10,608.30	3162.13	16,276.00	7300.00
Kumta	9821.14	2408.96	15,152.00	6693.00
Mundgod	10,848.78	6030.95	20,375.00	1275.00
Siddapur	10,066.04	1573.61	13,075.00	7964.00
Sirsi	14,347.56	4337.03	22,761.00	10,535.94
Supa	6036.36	2131.31	8758.55	1788.00
Yellapur	8014.98	2243.38	10,637.00	3650.00
Paddy (improved variety)				
Ankola	2889.91	742.50	3874.00	1545.00
Bhatkal	1523.29	315.86	2010.00	1094.00
Haliyal	7473.86	3074.39	11,511.00	3015.00
Honavar	1698.16	650.97	2473.00	406.00
Karwar	4232.36	999.74	6027.00	2997.00
Kumta	4522.90	1225.35	6340.00	2883.00
Mundgod	6351.72	4154.18	13,217.00	640.00
Siddapur	3851.71	702.39	5275.00	2900.00
Sirsi	9181.39	2652.26	12,095.00	4633.00
Supa	2438.72	1401.81	5468.00	938.00
Yellapur	5853.02	2136.59	9755.00	2631.00
Jowar				
Haliyal	218.86	56.82	300.00	138.00
Mundgod	431.00	271.03	1080.00	204.00
Sirsi	31.86	61.58	181.00	0.00
Supa	8.14	10.96	30.00	0.00
Yellapur	41.00	57.25	168.00	0.00
Maize				
Haliyal	110.57	52.52	220.00	56.00
Honavar	0.36	0.87	2.50	0.00
Mundgod	252.79	207.40	577.00	28.00
Siddapur	3.57	8.75	25.00	0.00
Sirsi	19.64	27.61	85.50	0.00
Supa	18.36	16.50	40.50	0.00
Yellapur	4.07	6.91	20.50	0.00
Oilseeds				
Ankola	1800.56	160.76	2142.00	1620.00
Bhatkal	2799.95	3532.12	11,420.00	717.00
Haliyal	276.29	101.72	449.26	124.25
Honavar	1780.12	363.05	2122.00	1027.00
Karwar	330.76	143.98	570.00	198.00
Kumta	1341.70	711.78	2739.92	130.00
Mundgod	180.23	95.99	318.00	56.00

(continued on next page)

Table 11 (*continued*)

Crop	Avg	Sd	Max	Min
Siddapur	279.50	197.14	616.00	60.47
Sirsi	676.54	175.50	951.00	397.00
Supa	28.66	16.31	47.00	3.00
Yellapur	52.56	27.48	111.00	29.00
Pulses				
Ankola	103.13	22.22	141.00	73.00
Bhatkal	185.67	39.82	248.00	132.00
Haliyal	1126.15	214.76	1419.00	794.00
Honavar	95.82	24.54	137.00	61.00
Karwar	54.24	34.28	109.00	25.00
Kumta	93.93	29.68	129.00	52.31
Mundgod	538.08	358.77	1365.00	247.00
Siddapur	496.90	573.99	1858.00	73.32
Sirsi	380.30	117.55	587.00	196.00
Supa	49.78	40.65	139.00	16.00
Yellapur	211.89	81.54	364.00	110.00
Ragi				
Ankola	8.57	6.19	21.00	0.00
Bhatkal	9.00	10.41	28.00	0.00
Haliyal	16.86	10.89	31.00	0.00
Honavar	6.71	4.83	14.00	0.00
Kumta	35.70	19.82	69.00	0.00
Mundgod	82.74	80.62	259.00	0.00
Siddapur	2.71	4.49	12.00	0.00
Sirsi	15.97	10.90	32.00	0.00
Supa	210.61	152.01	424.00	0.00
Yellapur	6.73	7.61	24.00	0.00
Sugar cane				
Ankola	4840.00	1109.79	6717.00	3658.00
Bhatkal	4756.04	2130.00	6717.00	50.26
Haliyal	32,852.29	10,118.43	47,520.00	14,286.00
Honavar	15,704.00	8109.91	35,250.00	10,348.00
Karwar	1940.86	1100.44	3500.00	928.00
Kumta	7684.18	3616.40	12,500.00	86.26
Mundgod	2932.29	3480.65	10,604.00	0.00
Siddapur	13,170.86	5861.12	22,776.00	5250.00
Sirsi				
Supa	11,955.00	5771.85	19,493.00	4425.00
Yellapur	6189.71	742.05	7308.00	4890.00

5.2. Agricultural residues

5.2.1. Paddy residues

Paddy (*Oryza sativa*) constitutes a major cereal crop (85.85%, 93,087 ha) in the Uttara Kannada District. Rice husk and stalks are the major residues of paddy cultivation. The potential availability of husk and stalk Talukwise is given in Table 12. The quality of husk depends upon the type of rice mill. In the single

Table 12
Energy from agricultural residues for fuel and fodder in lakh kWh

Crop	Production		Residues in tonnes		Energy (lakh kWh) that could be generated out of this waste	
	Average	Sd	Husk	Stalk	Husk–fuel	Stalk–fodder
Paddy (high yield variety)						
Ankola	11,489.82	3159.50	3431.89	11,486.32	119.64	400.41
Bhatkal	6739.34	785.40	2012.97	6737.29	70.17	234.86
Haliyal	17,194.45	6315.85	5135.80	17,189.21	179.03	599.22
Honavar	8202.86	2248.29	2450.11	8200.36	85.41	285.86
Karwar	10,608.30	3162.13	3168.59	10,605.07	110.46	369.69
Kumta	9821.14	2408.96	2933.47	9818.15	102.26	342.26
Mundgod	10,848.78	6030.95	3240.42	10,845.48	112.96	378.07
Siddapur	10,066.04	1573.61	3006.62	10,062.97	104.81	350.80
Sirsi	14,347.56	4337.03	4285.47	14,343.19	149.39	500.00
Supa	6036.36	2131.31	1803.00	6034.52	62.85	210.36
Yellapur	8014.98	2243.38	2393.99	8012.53	83.45	279.32
Total	113,369.65		33,862.31	113,335.09	1180.44	3950.86
Paddy (improved variety)						
Ankola	2889.91	742.50	863.19	2889.03	30.09	100.71
Bhatkal	1523.29	315.86	454.99	1522.83	15.86	53.09
Haliyal	7473.86	3074.39	2232.36	7471.58	77.82	260.46
Honavar	1698.16	650.97	507.22	1697.64	17.68	59.18
Karwar	4232.36	999.74	1264.16	4231.07	44.07	147.50
Kumta	4522.90	1225.35	1350.94	4521.53	47.09	157.62
Mundgod	6351.72	4154.18	1897.19	6349.79	66.14	221.35
Siddapur	3851.71	702.39	1150.47	3850.54	40.11	134.23
Sirsi	9181.39	2652.26	2742.38	9178.59	95.60	319.97
Supa	2438.72	1401.81	728.42	2437.98	25.39	84.99
Yellapur	5853.02	2136.59	1748.24	5851.24	60.94	203.97
Total	50,017.06		14,939.57	50,001.82	520.79	1743.06

(continued on next page)

Table 12 (*continued*)

Crop	Production		Residues in tonnes		Energy (lakh kWh) that could be generated out of this waste	
	Average	Sd	Husk	Stalk	Husk–fuel	Stalk–fodder
Jowar						
Haliyal	218.86	56.82		262.60		9.15
Mundgod	431.00	271.03		517.14		18.03
Sirsi	31.86	61.58		38.22		1.33
Supa	8.14	10.96		9.77		0.34
Yellapur	41.00	57.25		49.19		1.71
Total	730.86	457.64		876.92		30.57
Maize						
Haliyal	110.57	52.52	110.57	221.14	4.50	8.99
Honavar	0.36	0.87	0.36	0.71	0.01	0.03
Mundgod	252.79	207.40	252.79	505.57	10.28	20.56
Siddapur	3.57	8.75	3.57	7.14	0.15	0.29
Sirsi	19.64	27.61	19.64	39.29	0.80	1.60
Supa	18.36	16.50	18.36	36.71	0.75	1.49
Yellapur	4.07	6.91	4.07	8.14	0.17	0.33
Total	409.36		409.36	818.71	16.65	33.30
Oilseeds						
Ankola	1800.56	160.76	539.78		21.95	
Bhatkal	2799.95	3532.12	839.37		34.14	
Haliyal	276.29	101.72	82.83		3.37	
Honavar	1780.12	363.05	533.65		21.70	
Karwar	330.76	143.98	99.15		4.03	
Kumta	1341.70	711.78	402.22		16.36	
Mundgod	180.23	95.99	54.03		2.20	
Siddapur	279.50	197.14	83.79		3.41	
Sirsi	676.54	175.50	202.81		8.25	
Supa	28.66	16.31	8.59		0.35	
Yellapur	52.56	27.48	15.76		0.64	
Total	9546.86		2861.97		116.40	

Pulses						
Ankola	103.13	22.22		51.57		1.80
Bhatkal	185.67	39.82		92.84		3.24
Haliyal	1126.15	214.76		563.08		19.63
Honavar	95.82	24.54		47.91		1.67
Karwar	54.24	34.28		27.12		0.95
Kumta	93.93	29.68		46.97		1.64
Mundgod	538.08	358.77		269.04		9.38
Siddapur	496.60	573.99		248.45		8.66
Sirsi	380.30	117.55		190.15		6.63
Supa	49.78	40.65		24.89		0.87
Yellapur	211.89	81.54		105.94		3.69
Total	3335.89			1667.94		58.14
Ragi						
Ankola	8.57	6.19		4.29		0.15
Bhatkal	9.00	10.41		4.50		0.16
Haliyal	16.86	10.89		8.43		0.29
Honavar	6.71	4.83		3.36		0.12
Kumta	35.70	19.82		17.85		0.62
Mundgod	82.74	80.62		41.37		1.44
Siddapur	2.71	4.49		1.36		0.05
Sirsi	15.97	10.90		7.99		0.28
Supa	210.61	152.01		105.31		3.67
Yellapur	6.73	7.61		3.36		0.12
Total	395.61			197.81		6.90
Sugar cane						
Ankola	4840.00	1109.79	1462.83		59.49	
Bhatkal	4756.04	2130.00	1437.45		58.46	
Haliyal	32,852.29	10,118.43	9929.18		403.82	
Honavar	15,704.00	8109.91	4746.33		193.03	
Karwar	1940.86	1100.44	586.60		23.86	
Kumta	7684.18	3616.40	2322.44		94.45	
Mundgod	2932.29	3480.65	886.25		36.04	
Siddapur	13,170.86	5861.12	3980.72		161.90	

(continued on next page)

Table 12 (*continued*)

Crop	Production		Residues in tonnes		Energy (lakh kWh) that could be generated out of this waste	
	Average	Sd	Husk	Stalk	Husk–fuel	Stalk–fodder
Sirsi	8865.65	2341.35	2679.53		108.98	
Supa	11,955.00	5771.85	3613.24		146.95	
Yellapur	6189.71	742.05	1870.76		76.08	
Total	110,890.87		33,515.33		1363.07	
Cotton						
Haliyal	6376.75	2564.12		22,318.63		778.03
Mundgod	4406.33	2300.12		15,422.16		537.62
Siddapur	9.13	6.22		31.96		1.11
Sirsi	497.67	243.45		1741.85		60.72
Supa	124.57	43.56		436.00		15.20
Yellapur	591.37	231.12		2069.80		72.15
Total	12,005.82	5388.59		42,020.37		1464.83
Uttara Kannada total energy from agri. residues in lakh kWh					3197.35	7287.66

huller the husk is obtained in a fine broken state and is always mixed with bran and broken rice. This husk bran mix is used by the farmers as cattle feed and by mill owners as boiler fuel. In the sheller-huller or sheller and modern rice mills, the husk is free from bran and broken rice. The average higher calorific value of rice husk ranges from 2937.5 to 3461.31 kcals (the higher calorific value includes the latent heat of water vapour in the product of combustion — obtained with the help of a bomb calorimeter). The lower calorific value ranges from 2637.29 to 3161.25 kcals. Proximate analysis of paddy husk shows that the volatile matter ranges from 66.6–69.3%, fixed carbon in the range of 12.7–16.9% and ash in the range of 16.5–18.6%. Based on the quantity of paddy production in each Taluk, energy equivalent in kWh is computed for husk and stalk. Stalk is mainly used as fodder. The energy equivalent of paddy husk (both HY and improved variety) as indicated in Table 12 is about 1701.23 lakh kWh.

5.2.2. Bagasse

Sugarcane (*Saccharum officinarum*) is one of the important cash crops in Karnataka's economy. The area under sugarcane in Uttara Kannada is about 1682 ha with a production of 102,025 tonnes. Talukwise area, production and yield of sugarcane is listed in Table 10. While Table 11 provides quantities of bagasse available in the District. Bagasse is the fibrous residue left after the extraction of juice from sugarcane. The quantity of bagasse depends upon the fibrous content, and is in the range of 30–32%. Juice from sugarcane is used to manufacture jaggery. The bagasse produced is used for making jaggery as fuel along with logs of wood. The average gross calorific value of bagasse is about 3500 kcals. One tonne of bagasse generates about 2.5 tonnes of steam. Bagasse is being used to generate methane. One tonne of bagasse generates about 200 cu m of combustible gas. In the sugar industry bagasse is used for generating steam in the boilers to drive the prime movers as well as for boiling and concentrating juice. The quantity of bagasse available in Uttara Kannada is about 33,515 tonnes and its energy equivalent is 1363 lakh kWh.

5.2.3. Oil seed

Groundnut (*Arachis hypogea*) in terms of weight, is the most important oil seed crop ranking next to cotton. The Uttara Kannada District has about 5863 ha (5.48%) under oil seed crop. Depending upon variety, season and soil conditions about 30% of the groundnut pod consists of shell. On average about 2861.97 tonnes of shell is available in the District. The average higher calorific value of shell is about 4532.15 kcal/kg and the lower calorific value is about 4248.58 kcal/kg. The energy equivalent of the total available Groundnut husk is about 116.4 lakh kWh. Groundnut shells are also reported to be good raw materials for the manufacture of activated carbons for bleaching purposes, and compare favourably with other good quality carbons.

5.2.4. Maize residues

Maize cobs constitute about 30% of maize grain (*Zea mays*). The cobs are used

as fuel or as a supplementary feed for cattle. About 409.36 tonnes of maize husk and 818.71 tonnes of stalk (mainly used as fodder) are available. The energy equivalent of husk works out to be about 16.65 lakh kWh. While, residues of ragi (*Eleusine coracana*) also refereed as finger millet (197.81 tonnes), pulses (1667.84 tonnes), cotton (*Gossypium hirsutum*) (42020.37 tonnes) and jowar (*Sorghum vulgare*) (876.92 tonnes) are used mainly as fodder. Energy equivalents of these residues are listed in Table 12.

6. Bioenergy from horticulture

Next to paddy plantations crops such as areca (*Areca catechu*), cashew (*Anacardium occidentale*), coconut (*Cocos nucifera*), pepper (*Piper nigrum*) and cardamom (*Elletaria cardamomum*) occupy an important place. The area brought under these crops shows an upward trend during recent years. The cultivation of areca is confined to the Taluks of Sirsi, Siddapur, Honnavar, Kumta and Yellapur. In the coastal belt, coconut is the important cash crop. Talukwise area, production of areca, coconut and cashew are listed in Tables 13–15. Area under areca, coconut and cashew in Uttara Kannada are 8499 ha, 5685 ha and 1749 ha respectively.

6.1. Horticulture residues

6.1.1. Coconut residues

The fuel biomass of coconut palms are leaves (12/tree/year), inflorescence (12–15/tree/year), shells (100/tree/year), husk (100/tree/year) and leaf sheath. The weight of these constituents, per tree, are given in Table 16.

Coconut husk is generally used for making rope, coir products and also for mulching in coconut plantations in the Uttara Kannada District. Coir dust which constitutes 70% of husk, decomposes very slowly in the soil as its pentosan lignin ratio is less than 0.5. It absorbs about eight times its weight of water and parts with it comparatively slowly [28]. The plaited leaves of coconut palm are used for thatching houses, fencing and for making baskets. Unplaited leaves are also used for fencing, mulching and for shading nurseries. The lower hard portion of leaves is used as fuel, which constitute 40–50% of the total weight of leaf.

Coconut shells are mainly used for fuel and to a lesser extent for the manufacture of various domestic utensils, fancy items etc. The calorific value of shell is in the range of 4500–4800 kcals/kg. The commercial utilisation of coconut shell for the production of shell charcoal, activated carbon and shell flour is now gaining importance. The output of charcoal by ordinary processes is about 30% of the original shells. The average output has been found to be 35 kg charcoal from 1000 whole shells. Talukwise energy equivalent of coconut residues are estimated assuming 100% shells, 100% inflorescence, 30% husk and 40% of leaves would be available to use as fuel, (as listed in Tables 13–15). It is seen that coastal Taluks contribute a major share of 84.49% of the total. The energy

Table 13
Horticultural crop-Areca.
Area (in hectares), production (in tonnes) and net energy available (lakh kWh)

	Area (hectares)	Percentage share	Production (tonnes)	Leaves (tonnes)	Inflorescence (tonnes)	Nuts and husk (tonnes)	Leaf sheath (tonnes)	Energy: Husk (30%) + inflore + leaf sheath (50%) + leaf (50%)
Ankola	235	2.77	293.75	1443.49	1443.49	875.61	951.75	101.00
Bhatkal	234	2.75	292.50	2874.69	2211.30	871.88	947.70	150.21
Haliyal		0.00						
Honavar	922	10.85	1152.50	11,326.77	8712.90	3435.37	3734.10	591.85
Karwar	23	0.27	28.75	282.56	217.35	85.70	93.15	14.76
Kumta	459	5.40	573.75	5638.82	4337.55	1710.23	1858.95	294.64
Mundgod	77	0.91	96.25	945.95	727.65	286.90	311.85	49.43
Siddapur	2400	28.24	5280.00	29,484.00	22,680.00	8942.40	9720.00	1540.61
Sirsi	2925	34.42	6435.00	35,933.63	27641.25	10,898.55	11,846.25	1877.62
Supa	94	1.11	206.80	1154.79	888.30	350.24	380.70	60.34
Yellapur	1130	13.30	2486.00	13,882.05	10,678.50	4210.38	4576.50	725.37
Total	8499	100.00	16,845.30	102,966.73	79,538.29	31,667.27	34,420.95	5405.83

Table 14
Horticultural crop-coconut.
Area (in hectares), production (in tonnes) and net energy available (lakh kWh)

	Area	Percentage share	Nuts in '000 s	Leaves (tonnes)	Inflorescence (tonnes)	Husk	Nut/shells	Leaf sheath	Energy: Shell + 30% husk + leaf sheath + inflore + leaves (40%)
Ankola	641	11.28	7692.00	3772.93	699.20	1153.80	3030.65	396.14	278.55
Bhatkal	642	11.29	7704.00	3778.81	700.29	1155.60	3035.38	396.76	278.98
Haliyal	14	0.25	168.00	82.40	15.27	25.20	66.19	8.65	6.08
Honavar	1535	27.00	18,420.00	9035.01	1674.38	2763.00	7257.48	948.63	667.04
Karwar	785	13.81	9420.00	4620.51	856.28	1413.00	3711.48	485.13	341.13
Kumta	1200	21.11	14,400.00	7063.20	1308.96	2160.00	5673.60	741.60	521.47
Mundgod	53	0.93	636.00	311.96	57.81	95.40	250.58	32.75	23.03
Siddapur	45	0.79	540.00	264.87	49.09	81.00	212.76	27.81	19.55
Sirsi	373	6.56	4476.00	2195.48	406.87	671.40	1763.54	230.51	162.09
Supa	81	1.42	972.00	476.77	88.35	145.80	382.97	50.06	35.20
Yellapur	316	5.56	3792.00	1859.98	344.69	568.80	1494.05	195.29	137.32
Total	5685	100.00	68,220.00	33,461.91	6201.20	10,233.00	26,878.68	3513.33	2470.44

Table 15
Horticultural crop-cashew
Area (in hectares), production (in tonnes) and net energy available (lakh kWh)

	Area	Percentage share	Tonnes	Husk (tonnes)	Fuelwood (tonnes)	Energy: Husk + fuelwood
Ankola	304	17.38	212.80	319.20	1064.00	63.70
Bhatkal	188	10.75	131.60	197.40	658.00	39.39
Haliyal	10	0.57	7.00	10.50	35.00	2,.10
Honavar	340	19.44	238.00	357.00	1190.00	71.24
Karwar	140	8.00	98.00	147.00	490.00	29.33
Kumta	627	35.85	827.64	1241.46	2194.50	148.36
Mundgod	8	0.46	5.60	8.40	28.00	1.68
Siddapur	13	0.74	9.10	13.65	45.50	2.72
Sirsi	69	3.95	48.30	72.45	241.50	14.46
Supa	33	1.89	23.10	34.65	115.50	6.91
Yellapur	17	0.97	11.90	17.85	59.50	3.56
Total	1749	100.00	1613.04	2419.56	6121.50	383.45

equivalent of coconut residues for Uttara Kannada is about 2470.44 lakh kWh, with Honnavar 667.04 lakh kWh followed by Kumta 521.47 lakh kWh.

6.1.2. Areca residues

The fuel biomass of Arecanut palm are leaves (6–7/tree/year), inflorescence (4–5/tree/year), husk and leaf sheath.

1. Areca husk — husk is the outer cover of areca fruit. It constitutes about 60–80% of the total volume and weight of the fruits (fresh weight basis) [29]. Currently, this is being largely wasted in Uttara Kannada except for use as an inferior fuel and mulch. The husk fibers are predominantly composed of cellulose with varying proportions of hemicellulose (35–64.8%), lignin (13.0–26.0%), pectin and protopectin. These properties make it a good raw material in the manufacture of hard boards, paper boards, activated carbon etc. Properly composted husk could be a good organic manure. It consists of 1.0–1.1% N_2, 0.4–0.5% P_2O_5, and 1.0–1.5% K_2O. It has been estimated [30] that a

Table 16
Fuel biomass from coconut palm per year

Components	Productivity/tree	Biomass (kg)/tree
Leaves	12/tree/year	48.50
Inflorescence	12–15 tree/year	10.00
Shells	100/tree/year	14.91
Husk	100/tree/year	39.55
Leaf sheath		6.55
Total		119.51

lakh tonne of composted husk provides about 1000 tonnes of N_2, 500 tonnes of P_2O_5 and 1000 tonnes of K_2O. Also it is reported that husk is very resistant to microbial degradation because of the presence of ligno cellulose.

2. Leaf sheath — areca palm sheds about 5–6 leaves per year. About 34,420.95 tonnes of leaf sheath are available in the District (Talukwise availability is listed in Tables 13–15). The sheath measure about 75–85 cm long and 35–40 cm wide at the center and 15–20 cm at the stalk end. Freshly fallen leaves contain about 55–60% moisture. The major constituents of leaf sheath are cellulose (43%), crude fibre (33%) and ash (5%). About 34,420.95 tonnes of leaf sheath are available in the Uttara Kannada District. In Sirsi, Siddapur Taluks leaf sheath is also used as cattle feed by some farmers. From an organic manure point of view, it consists of 0.7% N_2, 0.3% P_2O_5, and 1.0% K_2O.

   In coastal Taluks like Honnavar, sheaths are used to manufacture hats for farm workers. In some places it is used to manufacture throw-away cups and plates, packing cases, leaf sheath plyboards, decorative vaneer panels and picture mounts.
3. Leaf — the quantity of areca leaves available is about 102,966.7 tonnes. At present, it is used for thatching and also as a mulch in areca gardens. The leaves are a good source of organic manure. Approximate composition is 0.94% N_2, 0.096% P_2O_5, and 1.0% K_2O.
4. Other residues such as inflorescence are used mainly as fuel. About 79,538.39 tonnes of inflorescence is available annually. With the assumption that 30% husk, 50% leaf sheath and 100% inflorescence is available for fuel, the energy equivalent computed from areca residues works out to be 5405.83 lakh kWh.

6.1.3. Cashew

The Cashewnut tree was introduced for the purpose of checking soil erosion on coastal lands and hill slopes. It does not grow satisfactorily at elevations higher than 300 m [31]. Cashewnut has gained commercial importance during the last two decades on account of the increased demand for its edible kernel and shell oil in the international markets.

The area under Cashew plantation in Uttara Kannada is about 1749 ha with an annual production of 1613 tonnes of Cashew kernels. Cashew shell husk is an important residue of cashew and the quantity available is about 2419.56 tonnes. Considering net primary productivity of Cashew wood from plantations as 3 t/ha/year, total quantity of fuel wood available annually is about 6121.5 tonnes. The energy equivalent of Cashew shell husk and fuel wood is 383.45 lakh kWh. Talukwise information of area under Cashew production, quantity of husk and fuel wood available annually are given in Tables 13–15.

7. Bioenergy from animal residues

7.1. Livestock

Livestock is an important component of the agro ecosystem. For instance, livestock provide the critical energy input to the crop lands that is required for ploughing, threshing and other farm operations. Animal dung provides essential nutrients required for soil fertility and crop yields in the form of organic manure. Uttara Kannada farmers are distinct example of practitioners with a mix of agriculture, animal care and silviculture which requires the intensive use of crop lands, grazing lands and forest lands adjoining the village (which forms part of the integrated village ecosystem). In this section, the quantity of animal residue available and the option of converting it to biogas for cooking purposes is discussed.

Data collected from Taluk's Veterinary Department regarding livestock population is tabulated in Tables 17–19. There are about 463,729 cattle, 100,786 buffaloes, 18.853 goats and 4997 sheep in Uttara Kannada. The quantity of dung yield per cattle varies from place to place. It is seen that cattle dung available per animal in the coastal Taluk is about 3–4.5 kg/adult animal, in the hilly Taluks of Sirsi and Siddapur it ranges from 8–10 kg/animal, buffaloes 12–15 kg, stall fed buffalo about 15–18 kg, hybrid ones about 15–18 kg. By considering lower figures (such as 3 kg per animal for coastal cattle, 8 kg/animal for Sirsi, Siddapur cattle, 12 kg/animal for buffaloes), the total cattle dung available is about 844,414.18 tonnes/year and total buffalo dung available is about 441,442.7 tonnes/year. With the assumption of 0.036 m^3 of biogas yield per kg of cattle/buffaloes dung [32], we estimate that total quantity of gas available (if all is used for biogas) is about 46,290.85 thousand m^3. It is estimated that per capita requirement of gas is about 0.34–0.43 m^3/day for domestic purposes. Which means, that gas generated by animal dung is sufficient to meet the requirement of 30% of the total population of Uttara Kannada District. Talukwise availability of gas and the percentage of the population's requirement computed is listed in Tables 17–19. The same is shown pictorially in Fig. 4. From this analysis it is evident that in hilly Taluks such as Sirsi, Siddapur and Yellapur biogas if opted, can meet the requirement of more than 50% of these respective Taluk's populations. It is seen that the dung yield in sheep is about 1.5 kg/day, goat is about 1.5 kg/day and pig is about 2.5 kg/day. Gas yield per kg of pig dung is about 0.062 m^3 and sheep and goat is about 0.054 m^3. As indicated in Tables 17–19 the total quantity of gas available from sheep, goat and pig is about 897,340 m^3. Livestock sustain on fodder from grasslands, agricultural residues and from forest lands. We now look at the quantity of fodder available in the District from various categories of vegetation.

7.2. Fodder availability

Litter production in forests under various vegetation types is estimated Talukwise and the same is listed in Table 20. While Table 21, is a compilation of

Table 17
Livestock population (Talukwise), estimated dung and gas yield per year

Taluk	Cattle			Total cattle dung produced (tonnes)	Buffalo			Total buffalo dung produced (tonnes)
	Male	Female	Total		Male	Female	Total	
Ankola	15,943	11,749	27,692	30,322.74	2951	4107	7058	30,914.04
Bhatkal	10,613	11,838	22,451	24,583.85	2936	3846	6782	29,705.16
Haliyal	21,978	17,118	39,096	85,620.24	3572	9635	13,207	57,846.66
Honavar	19,811	28,863	48,674	53,298.03	2103	4807	6910	30,265.8
Karwar	11,220	8932	20,152	22,066.44	3654	4144	7798	34,155.24
Kumta	18,269	19,066	37,335	40,881.83	2014	4831	6845	29,981.1
Mundgod	18,757	15,122	33,879	74,195.01	1331	4673	6004	26,297.52
Sirsi	44,298	48,670	92,968	203,599.92	3925	13,305	17,230	75,467.4
Siddapur	36,927	36,646	73,573	161,124.87	2451	9807	12,258	53,690.04
Supa	12,390	9178	21,569	47,235.45	2720	2100	4820	21,111.6
Yellapur	21,883	24,457	46,341	101,485.80	4263	7611	11,874	52,008.12
District:	232,090	231,639	463,729	844,414.18	31,920	68,866	100,786	441,442.68

Table 18
Livestock population (Talukwise), estimated dung and gas yield per year

Taluk	Total (cattle + buffalo)		No. of persons required	District total population	Percentage of population could use biogas
	Dung (tonnes)	Biogas 000 m^3			
Ankola	61,236.8	2204.52	17,764.1	91,310	19.45
Bhatkal	54,289	1954.40	15,748.6	129,017	12.21
Haliyal	143,467	5164.81	41,618.1	94,363	44.10
Honavar	83,563.8	3008.30	24,240.9	145,842	16.62
Karwar	56,221.7	2023.98	16,309.3	142,845	11.42
Kumta	70,862.9	2551.07	20,556.5	134,144	15.32
Mundgod	100,493	3617.73	29,151.7	77,939	37.40
Sirsi	279,067	10,046.42	80,954.3	152,935	52.93
Siddapur	214,815	7733.34	62,315.4	94,202	66.15
Supa	68,347.1	2460.49	19,826.7	99,519	19.92
Yellapur	153,494	5525.78	44,526.8	81,410	54.69
District:	1,285,857	46,290,85	373,012	1,243,526	30.00

Table 19
Livestock population (Talukwise), estimated dung and gas yield per year

Taluk	Sheep	Goats	Pigs	Waste produced in tonnes/year	Biogas '000 m^3	No. of persons required/yr
Ankola	46	458	2	277.77	17.22	138.77
Bhatkal	196	701		491.11	30.45	245.36
Haliyal	850	2230	987	2586.94	160.39	1292.43
Honavar	75	338	40	262.62	16.28	131.20
Karwar	357	303	286	622.33	38.58	310.91
Kumta	384	196	67	378.69	23.48	189.19
Mundgod	741	2779		1927.20	119.49	962.82
Sirsi	853	7245	55	4483.84	278.00	2240.11
Siddapur	415	3975		2403.53	149.02	1200.79
Supa	619	155	8	431.07	26.73	215.36
Yellapur	461	473	106	608.09	37.70	303.80
District:	4997	18,853	1551	14,473.16	897.34	7230.75

agro residues such as paddy, cotton maize, pulses stalk etc. It is found that about 208,918.67 tonnes of agro residues are available in the District.

7.3. Fodder demand

The average weight of cattle and buffalo is approximately about 200 and 260 kg respectively. Taking the daily fodder requirement at about 2.5% of body weight, the fodder requirement computed for the district is about 10.85 lakh tonnes. As indicated in Table 22, the total agro residue available is about 2.08 lakh tonnes. The balance of 8.77 lakh tonnes of fodder is being provided by forests and grass lands. The productivity of grass land is about 5–15 t/ha. In Sirsi, Siddapur and Yellapur the yield is as high as 15–60 t/ha. Grass is generally available during the monsoon period. In Uttara Kannada, land under permanent pasture is about 20,369 ha, and grass production is about 1.01 lakh tonnes. With the onset of the dry months, the grass availability declines and crop residues obtained from agriculture and leaf fodder obtained from trees, help to tide over the scarcity period. In some parts of Sirsi, at places like Banavasi, fodder crop such as sunhemp is grown during the kharif season as a second crop. The portion of fodder crops is left (about 25–30%) which in land provides the nutrient for rabi crop. This practice has yielded a higher yield of paddy and also helped in getting over fodder scarcity. In recent years croplands have been expanded onto grazing

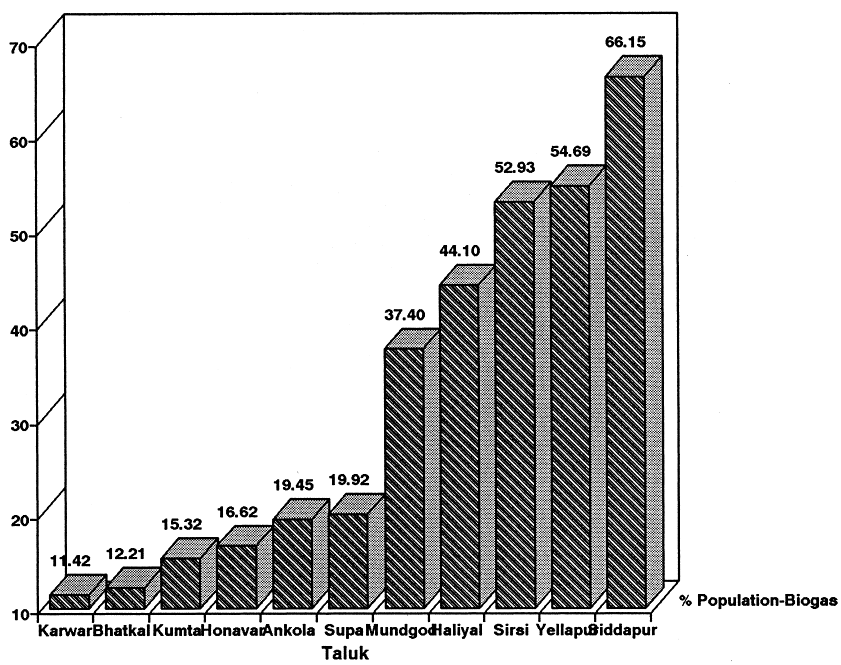


Fig. 4. Percentage of population requirement can be met with biogas option.

Table 20
Talukwise litter production in tonnes

Taluk	Forest (ha)	Area in hectares — under various vegetation				Coastal	Litter production–biomass production
		Dry deciduous	Moist deciduous	Evergreen	Semi evergreen		Total tonnes
Ankola	75,432.37		15,086.5	22,629.7	15,086.5	22,629.7	481,107.7
Bhatkal	25,390.46			5078.1	8124.9	12,187.4	120,706.2
Haliyal	59,099.78	23,639.9	23,639.9	11,820.0			571,258.5
Honavar	57,416.68		2870.8	20,095.8	17,225.0	17,225.0	351,935.5
Karwar	52,808.68		10,561.7	15,842.6	10,561.7	15,842.6	336,813.8
Kumta	39,187.59		7837.5	11,756.3	7837.5	11,756.3	249,938.4
Mundgod	51,167.36	28,142.0	23,025.3				513,362.1
Siddapur	62,274.6			40,478.5	21,796.1		510,807.4
Sirsi	103,226.57		15,484.0	46,452.0	41,290.6		868,496.7
Supa	160,608.71		40,152.2	120,456.5			1,391,273.0
Yellapur	113,429.56		51,043.3	62,386.3			1,016,385.6
District	800,042.36	51,782.0	189,701.3	356,995.7	121,922.4	79,641.0	2,680,656.3

Table 21
Bioresidues available from various crops

Crop: Paddy — high yield variety			Residues in tonnes, paddy (improved)		Total (from Paddy)		Total (paddy + others)	
	Husk	Stalk	Husk	Stalk	Husk	Stalk	Husk	Stalk
1	2	3	4	5	6 = 2 + 4	7 = 3 + 5	8 = 6 + 16	9 = 7 + 17
Ankola	3431.89	11,486.32	863.19	2889.03	4295.07	14,375.35	4295.07	14,431.20
Bhatkal	2012.97	6737.29	454.99	1522.83	2467.96	8260.12	2467.96	8357.45
Haliyal	5135.80	17,189.21	2232.36	7471.58	7368.16	24,660.79	7478.73	48,034.66
Honavar	2450.11	8200.36	507.22	1697.64	2957.33	9898.00	2957.69	9949.98
Karwar	3168.59	10,605.07	1264.16	4231.07	4432.75	14,836.14	4432.75	14,863.26
Kumta	2933.47	9818.15	1350.94	4521.53	4284.42	14,339.68	4284.42	14,404.49
Mundgod	3240.42	10,845.48	1897.19	6349.79	5137.61	17,195.26	5390.40	33,950.54
Siddapur	3006.62	10,062.97	1150.47	3850.54	4157.09	13,913.51	4160.66	14,202.42
Sirsi	4285.47	14,343.19	2742.38	9178.59	7027.85	23,521.78	7047.49	25,539.27
Supa	1803.00	6034.52	728.42	2437.98	2531.42	8472.51	2549.78	9085.18
Yellapur	2393.99	8012.53	1748.24	5851.24	4142.22	13,863.77	4146.30	16,100.21
Total	33,862.31	113,335.09	14,939.57	50,001.82	48,801.88	163,336.91	49,211.24	208,918.67

							Total (others)	
Crop: Ragi	Stalk	Jowar stalk	Maize husk	Maize stalk	Pulses stalk	Cotton stalk	Husk	Stalk
	10	11	12	13	14	15	16	17
Ankola	4.29				51.57		0.00	55.85
Bhatkal	4.50				92.84		0.00	97.34
Haliyal	8.43	262.60	110.57	221.14	563.08	22,318.63	110.57	23,373.87
Honavar	3.36		0.36	0.71	47.91		0.36	51.98
Karwar					27.12		0.00	27.12
Kumta	17.85				46.97		0.00	64.82

(continued on next page)

Table 21 (*continued*)

							Total (others)	
Crop: Ragi	Stalk 10	Jowar stalk 11	Maize husk 12	Maize stalk 13	Pulses stalk 14	Cotton stalk 15	Husk 16	Stalk 17
Mundgod	41.37	517.14	252.79	505.57	269.04	15,422.16	252.79	16,755.27
Siddapur	1.36		3.57	7.14	248.45	31.96	3.57	288.91
Sirsi	7.99	38.22	19.64	39.29	190.15	1741.85	19.64	2017.49
Supa	105.31	9.77	18.36	36.71	24.89	436.00	18.36	612.68
Yellapur	3.36	49.19	4.07	8.14	105.94	2069.80	4.07	2236.44
Total	197.81	876.92	409.36	818.71	1667.94	42,020.37	409.36	45,581.76

Table 22
Fodder requirement in Uttara Kannada

Taluk	Cattle total	Buffalo total	Cattle body wt: 200 kg, Buffalo: 260 kg, total body weight (tonnes)	Fodder demand @ 2.5% of body wt. (tonnes)
Ankola	27,692	7058	7373.48	67,283.01
Bhatkal	22,451	6782	6253.52	57,063.37
Haliyal	39,096	13,207	11,253.02	102,683.81
Honavar	48,674	6910	11,531.4	105,224.03
Karwar	20,152	7798	6057.88	55,278.16
Kumta	37,335	6845	9246.7	84,376.14
Mundgod	33,879	6004	8336.84	76,073.67
Sirsi	92,968	17,230	23,073.4	210,544.78
Siddapur	73,573	12,258	17,901.68	163,352.83
Supa	21,569	4820	5566.94	50,798.33
Yellapur	46,341	11,874	12,355.35	112,742.57
District:	463,729	100,786	118,950.21	1,085,420.67

and forest lands. Reduction of grazing land areas has resulted in overgrazing in the remaining grazing lands, turning them to wastelands. To find fodder, animals now graze heavily in forest land. In the area under forest about 50% have either closed canopy or are inaccessible. This means that the balance of 50% of forest has to meet 7.75 lakh tonnes of fodder. Whenever forest is logged, grazing animals suppress all regeneration and gradually the logged forest land turns into wasteland. The grazing pressure on forests has resulted in the depletion of grass, natural regeneration and has resulted in ecological imbalance. This necessitates the need for an integrated planning approach at the village to meet the growing demands of fuel and fodder. Fodder demands can be met by growing suitable fodder crop as has been successfully tried in Banavasi by some progressive farmers.

From the discussion of fuel and fodder availability, it is evident that to bring down further degradation of the resource base and hence ecological imbalance, the following are necessary: (1) enhancement of the total natural resource base, (2) production of basic biomass needs and optimal use of biomass for various end uses like in the domestic sector and agro processing sector through fuel efficient devices, (3) production of fuel and fodder biomass from degraded lands.

In the next section we discuss some of the alternative devices, which help in the optimal utilisation of bio residues and their technical and economical feasibility in the context of the village ecosystem.

8. Techno economic analyses of bioenergy systems

The fundamental forms of bioenergy use are:

1. The traditional domestic use for household cooking, lighting and water heating (for bathing). The efficiency of conversion of the biomass to useful energy is between 5–15%.
2. The rural industrial use in agro processing, bricks and tiles and pig iron where the biomass is considered as a free energy source. There is generally little incentive to use the biomass efficiently so conversion of feedstock to useful energy commonly occurs at an efficiency of 15% or less.
3. Biological conversion including anaerobic digestion for biogas production and fermentation for alcohol.

The overall efficiency of biomass utilisation depends on the moisture content of the fuel and the type of stoves used. Freshly cut wood contains about 25–60% moisture. The removal of a kilogram of water from wood involves an expenditure of about 620–670 kcals. It is noticed that a reduction of 25% moisture in fuel wood would cause a saving of nearly 15% of the fuel wood. The most common method adopted in Uttara Kannada for the removal of moisture is solar drying. Normally wood is lopped and collected from forests in the summer season and dried in an open space for usage during the monsoon. However, over drying also has its own adverse effects such as fire hazards etc. It is observed that dried wood

with a moisture content of 8% releases heat too fast and the whole log tends to burn, bringing the flame out of the stove.

8.1. Fuel efficient stoves

The most commonly used stoves in most households for cooking, are either mud stoves or three stone stoves also referred as traditional stoves (TCs). The efficiency of these stoves is less than 10%. Applying the principles of combustion and heat transfer, fuel efficient wood and other biomass burning designed by ASTRA [33] also known as Astra stoves or improved cook stoves (ICs). In Astra stoves complete combustion of fuel wood with as little excess air as practicable, generates the highest temperature of flue gases. In ICs, the combustion of fuel wood is carried out over a grate in an enclosed fuel box with ports of suitable size for entry of air. The grate helps in the entry of air below the fuel bed to burn the char as well as for the separation of ash from fuel. The air required for burning the volatile matter released as a consequence of heating the fuel (also referred to as secondary air), enters through a port at a level slightly above the grate. Heat gets transferred to pans by the mechanism of conduction convection and radiation. Fuel efficiency studies conducted in 82 households of a cluster of villages in the Sirsimakki microcatchment of Sirsi Taluk have shown that the fuel needed for cooking is about 1.92 (avg) $\pm$ 1.02 (Sd) kg per person per day for cooking in traditional stoves while in ICs about 1.1 (avg) $\pm$ 0.78 (Sd) kg per person per day. Which, means that there is a saving of about 42% in the quantity of fuel used by switching over to ICs from TCs. The average fuel consumption for water heating in the traditional stoves (efficiency is about 10–16%) is about 1.68 (avg) $\pm$ 0.80 (Sd) kg/person/day. While, in improved stoves (efficiency is about 35–60%), it is about 1.36 (avg) $\pm$ 0.63 (Sd) kg/person/day. This result is based on a sample study of 104 households, shows a potential of 19–24% saving in improved design. All traditional stoves in these villages are without a chimney. With the chimney, the efficiency of the stove increases and is about 22%. In improved stoves the fuel is allowed to burn over a cast iron grate. Air required for burning is allowed through the grate so that combustion is controlled. The rate of burning in improved stoves is about 30 min for 50 l (to a temperature of 45–50°C).

8.2. Biogas technology

Biogas is a product of anaerobic fermentation of organic matters, and consists of about 60–70% methane, 30–40% carbon-dioxide etc. The input materials for biogas digesters are the wastes that are found locally such as animal dung, agricultural residues and leaf litter from forests. The residues are introduced into a closed digester, where, without the presence of free oxygen, the responsible micro organisms work successively to convert complex organic matter into CH_4, CO_2, H_2, H_2S, etc. The optimum conditions for biogas production are: temperature 30–35°C, Ph 6.8–7.5, carbon:nitrogen ratio 20–30, solid contents 7–9%, retention time 20–40 days. Among these parameters, temperature is the most difficult or

costly to control. The gas formation virtually stops when the temperature drops below 10°C. The retention time decides the rate at which the waste is digested. The longer the time, the larger the volume of gas produced from a given amount of waste and vice versa. Thus if the available amount of input materials is limited, a bigger digester can be adopted to more fully exploit the gas potential; and where the waste is abundant, the waste can be fed at a higher loading rate into a small digester to maximise the gas production per unit volume of the digester. The optimum retention time depends on the temperature. In practice, a longer retention time is usually adopted to cope with cool seasons. There are various designs of biogas digesters such as:

1. Floating gas holder type designed by Kadhi and Village Industries Commission [34].
2. Optimised design developed by Application of Science and Technology to Rural Areas (ASTRA) at our institute [35].
3. Fixed dome type designed by University of Agricultural Sciences — Bhagyalaxmi design.
4. Raitabandu Biogas Plant — designed by a farmer from Sagar Taluk, Shimoga District to suit the needs of the Malnad region.

8.2.1. Biogas usage

Biogas can be used for many purposes, mainly for cooking and lighting in rural area. Biogas can be burned with a gas mantle or can be converted to electricity using a dual mode engine. The per capita requirement of gas for cooking is in the range of 0.34–0.43 m^3/day (efficiency of a standard burner is about 60%). The gas requirement to generate one unit of electricity (kWh) is about 0.54 m^3. The calorific value of 1 m^3 of gas is about 4713 kcals. Relative values of biogas compared with other energy sources are listed in Table 23. The potential of Biogas in hilly Taluks of the Uttara Kannada District is quite appealing. As indicated in

Table 23
Biogas value compared with other energy sources[a]

Relative calorific value	Relative monetary values
1 m^3 biogas	1.00
3.6 kg fuelwood	0.88
1.5 kg charcoal	1.28
5 kWh electricity	3.00
13 kg cowdung	1.30
0.6 l kerosene	2.34

[a] Costs: Kerosene Rs. 3.90 per litre (through public distribution system); Fuelwood Rs. 24.60 per quintal (price in Government Fuelwood Depot's at Kumta); Electricity Rs. 0.60 per kWh, Cowdung Rs. 0.10 per kg.

Tables 17–19, biogas can meet the cooking requirement of at least 30% of the total District population.

8.2.2. Biogas as substitute for fuel wood

A socio economic survey conducted in the villages of Kumta, Sirsi, Siddapur and Ankola have shown that the per capita requirement of fuel wood is around 0.7–1.1 t/year (the details of survey will be spelled out based on land holding, economic status and seasonal constraints in the next section). If 30% of the population opts for biogas, then the fuelwood saved in the District would be in the range of 2.6–4.10 lakh t/year.

By switching over to biogas, the drudgery involved in the collection and transport of fuel wood (which takes about 5–6 h per day) gets reduced, and savings in cooking time reduces from 4–6 h in the case of fuel wood stoves to 1.5–3 h a day.

8.2.3. Electricity generation

The decentralised electricity generation system by a community biogas plant was tried out in 1987 in Pura village, Kunigal Taluk, Tumkur District [36] for illumination and drinking water facilities. Because of multiple advantages like better illumination facility than kerosene lamps, convenient method of drinking water supply, better fertilizer without pathogen and weeds (due to anaerobic condition and long retention time in closed digester) in the form of sludge, the biogas system is accepted and maintained by villagers. A 5 kW electric generation unit using a biogas-diesel engine — genset system, caters for the needs of the pumping of domestic water and illumination during the evening (for 4 h). Two youths have been trained to maintain and manage the system. This community system provides revenue for the village to the extent that the total revenue received for outputs exceeds the expenses for diesel and dung charges (paid to villagers). Detailed economic analyses carried out based on the life cycle costing method, shows that a 4.3 h/day capacity utilisation, the cost of electricity is Rs. 2.75 kWh. It is noticed that as capacity utilisation increases to 15 h/day the cost per kWh is about Rs. 1.40. Comparison of the decentralised biogas system with a nuclear power station by Reddy and Balachandra [37] shows that in a capital starved situation where the real discount rates are high, the cost per kW of installed capacity is lower for biogas systems compared to nuclear power plants.

This review of bioenergy production from animal residues has shown that potential solutions do exist but there are very few in practical operation. The economics would ultimately depend on local conditions, requirements, the provision of subsidies etc. If farmers are forced/convinced to treat the residues for biogas prior to disposal to compost pits, it would be a valuable way to conserve fuelwood and improve the cooking environment in the kitchen.

8.3. Energy plantations

Technically speaking, energy plantations mean growing select species of trees

and shrubs which are harvestable in a comparably shorter time and are a specific means of fuel. The fuel wood may be used either directly into wood burning stoves and boilers or processed into methanol, ethanol and producer gas. These plantations help to provide wood for the purposes of cooking in homes and for industrial use so as to satisfy local energy needs in a decentralised manner [38]. The energy plantations provide almost inexhaustible renewable sources (has a total time constant of 3–8 years only for each cycle) of energy which is essentially local and independent of unreliable and finite sources of fuel. The attractive features of wood are (a) its heat content is similar to that of Indian coal; (b) wood is low in sulphur and is not likely to pollute the atmosphere; (c) ash obtainable from burning is a valuable fertiliser; (d) utilisation of erosion prone land for raising wood plantations helps to reduce wind and water erosion, thereby minimising hazards from floods, siltation, loss of nitrogen and minerals from soil; (e) helps in rural employment generation: it is estimated that an acre of energy plantation provides a job for at least three persons regularly. The selection of multipurpose species provides a number of by-products like oils, organic compounds, fruits, edible leaves, forage for livestock etc. Data collected from the Forest Department (plantations in Kumta and Sirsi Taluks under the Social Forestry Programme) reveals that annual woody biomass available is in the range of 11.9–21 t/ha/year. An energy forest raised at Hosalli village, Tumkur District to support wood gasifier plant has an annual yield of 6 t/ha/year.

8.4. Biomass fired steam power generation system

Biomass fuelled steam power systems, providing electricity as well as process heat, have been utilised for many decades in most countries of the world. Such systems have found widespread applications in areas such as paper and pulp, plywood and metallurgical industries. In such a system, utilising the energy in the biomass fuel through the process of direct combustion generates steam for driving a steam engine or turbine [39]. The efficiency of these devices is around 35%. In one of the studies on biomass fire steam power systems [40], results show that for systems utilising biomass fuels 0 and 60% (wet basis), and excess air rates between 0 and 200%, boiler efficiency ranging from 84 to 49%, steam engine efficiency from 18 to 13%, and overall plant efficiencies from 11 to 8.4%, the electricity fuel ratio between 0.7 and 0.2 kWh/kg cost per unit of electricity ranges from 24 to 39 paise.

8.4.1. Land requirement for energy plantation (and hence biomass fired thermal system)

Casuarina plantation with a yield of 6 t/ha/year and a growth cycle of 10 years is considered to compute land requirement for setting up a 1000 MW thermal power station. Assuming the calorific value of wood as 4670 kcals/kg, load factor of thermal plant as 0.5, thermal efficiency 35%, we compute land requirement as follows:

Total yield of harvested area	= 60 t/ha/year
Heat value/ha:	= 280.2×10^6 kcals/year/ha
	= 326.43×10^3 kWh (th)/year/ha
	= 114,251.55 kWh (elec)/year/ha
Power generated/ha at 0.5 load factor	= 26.08 kW/ha
Area needed for 1000 MW	= 38,336.46 ha
Total area	= 383,364.6 ha
Area to be harvested/day	= 105 ha/day
Nursery area required	= 1918 ha

The area required for setting up a 1000 MW power station for different wood species at different yield rate have been computed and tabulated in Table 24. *Casuarina* species with yield of 6–11 t/ha/year and a growth cycle of 10 years requires land of 3833.64–2091.07 km^2 to support a 1000 MW thermal station. Similarly, *A. auriculiformis* with a yield of 11–36 t/ha/year requires land of 2091–638.9 km^2.

8.5. Cost of wood based power station

Considering the life of thermal plants as 30 years, at 10%, capital recovery per year is computed. Cost of thermal station's equipment and civil cost works out to be Rs. 4.4 crores/MW. Assuming the cost of wood to be as Rs. 150 per tonne and annual O and M costs at 1% capital cost of machinery, the cost per unit of electricity comes to Rs. 0.98 (for yield of 6 t/ha/year), 0.69 (for 13.5 t/ha/year yield).

8.6. Scope for wood based power generation in the Uttara Kannada District

If we convert the present waste/barren land of 20,068 ha in the District to energy plantation, after 4–5 years the production of plantation is sufficient to support a 415 MW wood based power station.

8.7. Wood gasification

Biomass gasification is basically conversion of solid biomass (that is wood/ wood waste/agricultural residues etc.) into a combustible gas mixture normally called producer gas or low Btu gas. The process is typically used for woody biomass and it involves partial combustion of such biomass. Partial combustion process occurs when the air supply is less than adequate for the combustion of biomass to be completed. Partial combustion produces carbon monoxide (CO) as well as hydrogen (H_2) — both are combustible gases. Conversion to gas results in a loss of energy up to 25%. Use of gas can be highly efficient and hence overall efficiency could be very high. The gas can be fed directly into internal combustion engines (IC engines) thereby it could save

Table 24
Area required for a 1000 MW thermal power station (species wise)

Species	Annual yield/ha	Growth cycle	Total yield t/ha/year	kWh (th) kWh/year/ha	El energy kWh/year/ha	Power (ha)	Area reqd for 1000 MW/ha	Total area (growth Cy.) ha	Area to be harvested per day (ha)	Nursery (ha)
Casuarina	6	10	60	326,433.0	114,251.6	26.08	38,336.46	383,364.60	105.03	1916.82
Casuarina	11	10	110	598,460.5	209,461.2	47.82	20,910.80	209,107.96	57.29	1045.54
Eucalptus	6.5	8	52	282,908.6	99,018.0	22.61	44,234.38	353,875.02	121.19	2211.72
Eucalptus	13	8	104	565,817.2	198,036.0	45.21	22,117.19	176,937,51	60.60	1105.86
Eucalptus	20	8	160	870,488.0	304,670.8	69.56	14,376.17	115,009.38	39.39	718.81
A. auriculiformis	11	8	88	478,768.4	167,568.9	38.26	26,138.50	209,107.96	71.61	1306.92
A. auriculiformis	21	8	168	914,012.4	319,904.3	73.04	13,691.59	109,532.74	37.51	684.58
A. auriculiformis	36	8	288	1,566,878.4	548,407.4	125.21	7986.76	63,894.10	21.88	399.34
Fuelwood	6.5	40	260	1,414,543.0	495,090.1	113.03	8846.88	358,875.02	24.24	442.34
Fuelwood	13.5	40	540	2,937,897.0	1,028,264.0	234.76	4259.61	170,384.27	11.67	212.98
Fuelwood	27	40	1080	5,875,794.0	2,056,527.9	469.53	2129.80	85,192.13	5.84	106.49

commercial fuels. Also, it can be employed at any scale (about few kilowatts), and hence is ideally suited for decentralised applications — shaft power, electricity or thermal energy. In case of shaft power/electricity, the gas is basically burnt inside an engine (diesel-based compression ignition engine) with a pilot diesel injection to start combustion.

Biomass gasification provides a valuable fuel for both mobile and non mobile uses. Producer gas can replace natural gas, gasoline or fuel oils used to make steam for generating electricity, fire boilers and produce heat for industries and homes fuel, and for internal combustion engines for a wide array of purposes. Gasification is an efficient way of extracting heat from biomass. It is estimated that for each 100 kcal of potential energy in solid fuels, gasification can extract about 80 kcal in hot, raw gas [41]. This is more efficient than many devices that burn biomass directly in a hearth or fire box. Producer gas can be piped short distances and used for industrial purposes such as to fuel kilns — brick kilns, ceramics, glass pottery, etc. or for boilers in rice mills, saw mills, cashew industry or for power generation. In any case the producer gas for heat, the burner, must be designed for operation on low energy gas.

The function of the gasifier is to convert solid carbonaceous fuel, such as wood into combustible gases by a combination of oxidation, pyrolysis and reduction processes [42]. The major chemical reaction taking place are both exothermic ($C+O_2- > CO_2$, $C+0.5O_2- > CO$) and endothermic ($C+H_2O- > CO+H_2$, $CO_2+C- > 2CO$). In order to effectively carry out these reactions, the solid fuel passes through the following zones: drying, pyrolysis, combustion and reduction. In the drying zone the temperature is around 150°C, moisture in the biomass is driven off. In the pyrolysis zone, at 400°C thermal break down of wood/bio residues take place in the absence of air resulting in the formation of methanol, acetic acid and heavy hydro carbon including tar. The solid material left after the pyrolysis process is primarily fixed carbon in the form of charcoal. The pyrolysis material along with the gases and the organic vapors produced, passes through the combustion zone. In the combustion zone an exothermic reaction takes place and the heat released is used for sustaining both the pyrolysis and the reduction reactions. The temperature in this zone ranges from 1000–1500°C. The combustion zone has controlled introduction of air.

By forcing the vapors through the narrow area directly underneath the combustion zone, organic liquids and tar formed in the pyrolysis zone are cracked. In the cracking process the heat intensity increases. The gases thus formed are drawn to the reduction zone where an endothermic reaction takes place. The mixture of final product gases (producer gas) consisting of 18–25% CO, 13–15% H_2, 3–5% methane (CH_4), 0.2–0.4% heavy hydro carbon, 5–10% CO_2, 45–54% N_2, 10–15% H_2O and particulate matter is drawn into the clean up system at about 250°C. In the cleanup system the gas is cooled and cleaned to remove particulate and later it is introduced into the engine. Commercially available biomass gasification systems for power generation cover the range of 3–500 kW. The major relevant power generation in a decentralised manner are:

1. Village electrification in remote rural terrains which have adequate biomass resources (like villages Yan, Sandolli, Malavalli, Muttolli, Kodambale, Yedtare, Chimmoli, Medine, Morshe, Mudnalli, Kurigadde, Algar, Bangane, Kalve, Hebbail etc. in Kumta and villages Mogadde, Audhal, Kodigar, Menshi etc in Sirsi Taluk).
2. Energisation of number of pumpsets located in a cluster.
3. Captive power for industrial units located in rural areas and having extensive land area which can be devoted for energy plantations.
4. Captive power for industries that have biomass waste process such as paper mills, saw mills, rice mills etc.

8.8. Wood gasifier based electricity system

Community wood gasifier installed at Hosalli by our Institute [36] demonstrate that if managed properly, these units can be self sustaining and technically and economically feasible decentralised systems. The main features of this system are:

1. 5 kW wood gasifier-diesel system is installed at Hosalli — a non electrified village in the Tumkur District and is in operation since 1988. This system meets the lighting (for 4–5 h/day) and drinking water requirement of all (43) households.
2. An energy plantation in 2 ha village land has been raised (1987) consisting of *Leucaena leucocephalla, Dalbergia sisso, Eucalyptus* hybrid, *Cassia saimea, Acacia auriculiformis, Casuarina equisetifolia* with a density of 6600 plants/ha and approximate annual productivity of 6 t/ha/year.
3. The annual wood requirement for the gasifier is 5.1 tonnes at the rate of 1.2 kg of wood/kWh. Households are provided with two electrical lighting points of 40 and 25 W bulbs. Water is pumped using a 2 kW submersible pump from a borewell at a depth of 87 m for drinking and domestic use. Apart from this, energy is used for 9 street lamps for public lighting and a floor mill for milling grains. This system is being managed (technical and financial management) by three trained village youths.
4. Diesel replacement up to 85% is achieved under favorable operating condiitons.

The capital cost of gasifier, engine, generator, accessories, wood chipping machinery, energy forest and building is about Rs. 63,600. The life of gasifier and engine is considered to be 50,000 and 20,000 h respectively. At an operational level annual maintenance cost is taken as 5% and 10% of the cost for the gasifier and engine. Economic analysis carried out using the discounted cash flow techniques (NPV) method (considering total life cost and benefits) show that at the current level of operation of 4 h per day the cost per unit of electricity is about Rs. 3.50/kWh. However analyses show that cost per kWh can be reduced to Rs. 2.50 when the hours of operation is increased to 20 h per day.

8.9. Scope for energy plantation in Uttara Kannada

As per land use statistics, it is seen that about 20,068 ha of land is barren/degraded due to human pressure, grazing pressure etc. Assuming productivity of 6 t/ha/year, the fuelwood available from energy plantations grown in wastelands is about 120,408 tonnes. We have seen earlier through the wood gasification mode of power generation, that we can generate 1 kWh per 1.2 kg of fuel wood. This means that from wasteland plantation we can expect 100.34 million units of electricity annually. From this experience, it is evident that the gasification programme can be expanded tremendously by considering the integration of large scale plantation on sub standard soil/barren wasteland with fast growing tree species. The Kharif crop is not grown in Uttara Kannada in most of the Taluks because of the lack of proper irrigation facilities. Irrigation can increase production manifold to that obtained under rain fed conditions. The approach of combining biomass production and gasification will result in many benefits such as wasteland utilisation, energy supply and employment generation. This would help the rural population to be energy independent from shortages of oil and the fluctuating electricity supply from the centralised option. Realising the benefits of the integrated approach, the planning machinery of the State Government should take up implementing energy plantation and power generation through nodal agencies, the voluntary sector and universities.

9. Conclusions

Based on the detailed investigation of biomass resource availability and demand, we can categorise the Uttara Kannada District into two zones (a) Biomass surplus zone consisting of Taluks mainly from the hilly area, (b) Biomass deficit zone, consisting of thickly populated coastal Taluks such as Bhatkal, Kumta, Ankola, Honnavar and Karwar. Fuel wood is mainly used for cooking and horticulture residues from coconut and arecanut trees are used for water heating purposes. The present inefficient fuel consumption could be brought down by the usage of fuel efficient stoves. Availability of animal residues for biogas generation in Sirsi, Siddapur and Yellapur Taluks gives a viable alternative for cooking, lighting, fuel and a useful fertiliser. However to support the present livestock population, fodder from agricultural residues is insufficient in these Taluks. There is a need to supplement the fodder availability with fodder crops as successfully tried in the Banavasi village by some progressive farmers. Bioenergy experiences all the useful kinds of problems that affect most economic development projects. Lack of capital, skilled labour and service backups are serious impediments to the progress of alternate devices such as fuel efficient stoves, biogas, wood gasifier etc. Even of serious concern is the lack of coordinated effort/approach and integrated planning approach among various bureaucratic setups and ministries. These are the main hurdles to the successful implementation of biomass cultivation projects and the development of bioenergy.

Policies are to be formulated to remove the constraints at a local/regional level. Policies must engender the communication between the different institutions and government sectors involved with the establishment of a significant and sustainable biomass energy programme that is the agricultural, forestry, land planning and energy sectors. Hence, the prudent management practices of biomass production offers the opportunity to address multiple environmental concerns such as land degradation, bio diversity, CO_2 emissions, acid rain pollutants and local and regional health problems.

Acknowledgements

We thank our colleagues Dr. D.M. Bhat and Prof. M.D. Subashchandran for providing us useful reference materials and valuable tips on various aspects related to Forestry, Biomass productivity, Minor forest products etc. Our thanks to Mr. Ramesh and Mr. Bhat, Karnataka State Council for Science and Technology, Bangalore for their kind help in digitising maps and for the computation of area under various vegetation types. We thank the Forest Department for their positive support during field studies. Forest Department officials at Bangalore, Sirsi, Kumta and Honnavar provided useful statistical information required for this research. This research was funded by the Ministry of Environment and Forests, Government of India and the Indian Institute of Science.

References

[1] Hall DO. Biomass energy. Energy Policy 1991;19(8):711–37.
[2] Hall DO, Rosillo-Calle F. Why biomass matters. Biomass Newsletter (Special Issue) 1991;5(4).
[3] Hall DO, Rosillo-Calle F, Williams RH, Woods J. Biomass for energy: supply prospects. In: Johansson TB, Kelly H, Reddy AKN, Williams RH, editors. Renewables for fuel and electricity. Washington: Island Press, 1992 Chapter 14.
[4] Gadgil M. Eco development of selected microcatchments in the Bedthi–Aghnashini river basins of the Uttara Kannada District. In: An operational research programme for integrated development of microcatchments report. Bangalore, India: CES and KSCST, IISc, 1990.
[5] Buchanan FD. In: Journey through the northern parts of Kanara, vol. 1. Madras, India: Higginbothams and Company, 1801.
[6] Talbot WA. In: Forest flora of the bombay presidency and sind, vols 1 and 2. Poona, India: Government Photozincographic Press, 1909.
[7] Aitchison PE. The Soppinahosalli High Forest working plan. Bombay, India: Government Central Press, 1910 Block XXXVII.
[8] Mavinkurve GR. Working plan for inland coastal forests of Kanara western division. Bombay, India: Government Central Press, 1955.
[9] Shanmukappa G. Working plan for the unorganised forests of Sirsi and Siddapur. India: Karnataka Forest Department, Government of Karnataka, 1966.
[10] Shanmukhappa G. Working plan for the unorganised forests of Karwar and Honnavar divisions. India: Karnataka Forest Department, Government of Karnataka, 1977.
[11] Dhareshwar SS. The denuded condition of the minor forest in Kanara coastal tract. Ind Forester 1941;67:68–81.

[12] Chandran MDS. Vegetational changes in the evergreen forest belt of the Uttara Kannada District of Karnataka State, Ph. D. Thesis, Karnatak University, Dharwad, India 1993.
[13] Pascal JP, Shyamsundar S, Meher-Homji VM, Legris P. Vegetation map of Karnataka, Belgaum, Shimoga. Pondicherry, India: French Institute, 1983.
[14] Pascal JP. Explanatory booklet on the forest map of South India. Institut Francais de Pondicherry, Travaux de la section Scientifique et Technique, Hors Serie No. 18, Pondicherry, India 1986.
[15] Campbell JM. In: Kanara-Gazetteer of the Bombay presidency, vol. XV. Bombay, India: Government Central Press, 1883.
[16] Kamath SU. Uttara Kannada District. Bangalore, India: Karnataka State Gazetteer, Government of Karnataka, V.B. Soobbaiah & Sons, 1985.
[17] Pascal JP. Wet evergreen forests of the Western ghats of India. Pondicherry, India: Institut Francais de Pondicherry, 1988.
[18] Bhat DM. Litter production and seasonality in tropical moist forest ecosystems of Uttara Kannada District, Karnataka. Proc Indian Acad Sci (Plant Sci) 1990;100(2):139–52.
[19] Proctor J. Tropical forest litterfall I. problem of data comparison. In: Sutton SL, Whitemore TC, Chadwick AC, editors. Tropical rain forest: ecology and management. Oxford: Blackwell, 1983. p. 267–74.
[20] Garg RK, Vyas LN. Litter production in deciduous forest near Udaipur (South Rajastan) in India. In: Golley FB, Medina E, editors. Tropical ecological systems. Berlin: Springer-Verlag, 1975. p. 131–5.
[21] Rai SN, Proctor J. Ecological studies on four rain forests in Karnataka, India: II. Litterfall. Jour Ecol 1986;74:455–63.
[22] Songwe NC, Fasehun FW, Okali DW. Litterfall and productivity in a tropical rain forest, Southern Baakundu forest reserve, Cameroon. Jour Trop Ecol 1988;4:25–37.
[23] Greenland DJ, Kowal JML. Nutrient content of the moist tropical forest of Ghana. Pl Science 1960;12:154–64.
[24] Whitemore TC. Tropical rain forests of the Far East. Oxford, London: Clarendon Press, 1975.
[25] Rai SN. Above ground biomass in tropical rain forests of Western Ghats, India. Indian Forester 1984;110(8).
[26] Prasad SN, Hegde HG, Bhat DM, Hegde M. Estimates of standing biomass and productivity of tropical moist forests of Uttara Kannada District, Karnataka, India. CES Technical Report No. 19, CES, IISc, Bangalore, India 1987.
[27] Lele SM. Degradation, sustainability or transformation? A case study of villagers' use of forest lands in the Malnad Region of Uttara Kannada District, India. CES Technical Report No.27, CES, IISc, Bangalore, India 1993.
[28] Thampan PK. Handbook on coconut palm. Bombay, India: Oxford and IBH Publishing Co Pvt Ltd, 1981.
[29] Bavappa KVA, Nair MK, Kumar TP. The Arecanut palm. Kasargod, Kerala, India: Central Plantation Crops Research Institute, 1982.
[30] Bidappa KG. Utilisation of Arecanut waste. Arecanut Jour 1960;11:106–8.
[31] Jaiswal PL, Wadhwani AM, Rajinder S, Chhabra NN, Sarma PSN. Handbook of agriculture. New Delhi, India: Indian Council of Agricultural Research, 1980.
[32] Khandelwal KC, Mahdi SS. Biogas technology: a practical handbook. New Delhi, India: Tata McGraw-Hill Publishing Company Limited, 1986.
[33] Lokras SS. Fuel efficient stoves. CES Technical Report No. 65, p. 205–208. CES, IISc, Bangalore, India 1986.
[34] Directorate of Gobar Gas Scheme. Gobar gas: retrospect and prospects. Bombay, India: Khadi and Village Industries Commission, 1979.
[35] Subramanian DK. Energy utilisation in Karnataka. In: Saldanha CJ, editor. Karnataka state of environment report, 1984. p. 103–23.
[36] Ravindranath NH, Ramachandra TV. Renewable energy options for decentralised electricity generation. Encology 1996;11(2):27–32.
[37] Reddy AKN, Balachandra P. The economics of electricity generation from the Pura community

biogas system. In: Pai BR, Prasad MSR, editors. Power generation through renewable sources of energy. New Delhi, India: Tata McGraw-Hill Publishing Co, 1991.
[38] Vimal OP, Tyagi PD. Energy from biomass — an Indian experience. New Delhi, India: Gricole Publishing Academy, 1984.
[39] Tillman DA, Rossi AJ, Kitto WD. Wood combustion: principles, processes and economics. New York, USA: Academic Press, 1981.
[40] Prasad SB. Biomass — fired steam power cogeneration system: a theoretical study. Energy Conversion and Management 1995;36(1):65–77.
[41] Dayal M, Vimal OP, Singh KK. Biomass gasification in India — DNES activities. Biomass 1989;18:197–204.
[42] Talib A, Gross JR, Vigil JF, Grover PD, Rao TR, Gaur S, Anuradha N. Development and field testing of small biomass gasifier — engine systems in India — a project report. The Mitre Corporation, Virginia 22102-3481, USA 1987.
[43] Rai SN, Proctor J. Ecological studies on four rainforests in Karnataka: 1. Environment, structure, floristics and biomass. Journal of Ecology 1986;74:439–54.